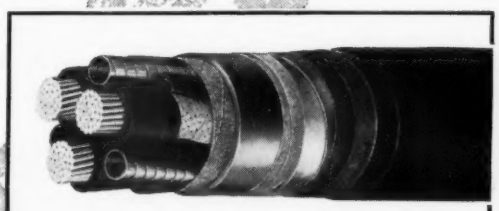
Water Power
INTERNATIONAL DEVELOPMENT OF HYDRO-ELECTRIC POWER
OCTOBER 1958

POWER

This was a tense moment for Herakles. His sixth labour for the Argive king Eurystheus was to destroy the man-eating birds of Lake Stymphalia. How well the sculptor has captured the feeling of power.

In our modern world, power — electrical power — is the great motivator of our industries, the light and warmth of our homes. And wherever electricity comes from, wherever it goes, Henley cables carry it surely and safely. No manufacturer has more experience in the design and manufacture of supertension cables up to 132 kV.

Herakles the Archer, *by Antoin Bourdelle*
Musée d'Art Moderne, Paris.



33 kV 3-CORE OIL-FILLED CABLE

BY APPOINTMENT TO HER MAJESTY THE QUEEN ELECTRIC CABLE MANUFACTURERS

POWER CABLES by HENLEY

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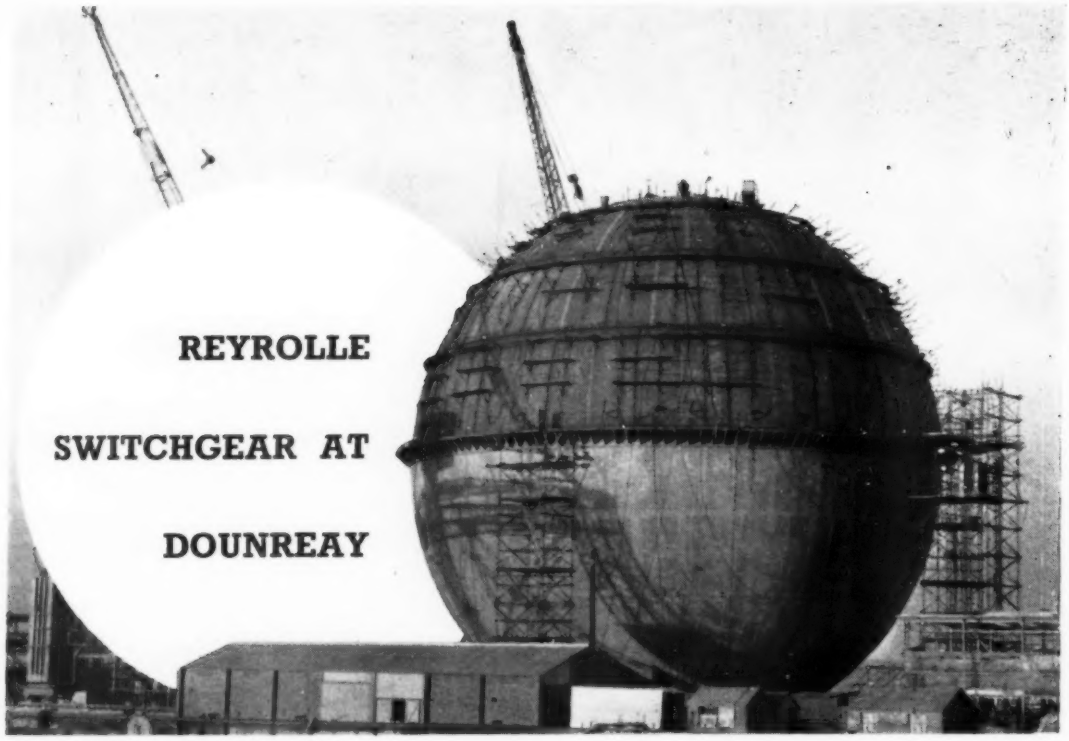
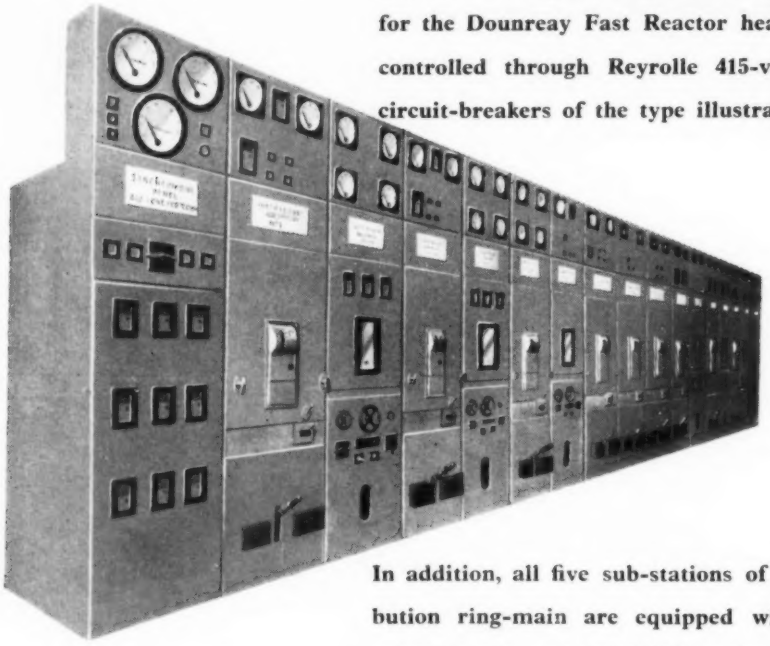


REYROLLE SWITCHGEAR AT DOUNREAY

Photograph by courtesy of the U.K.A.E.A

The electro-magnetic liquid-metal pumps and other services for the Dounreay Fast Reactor heat-exchanger system are controlled through Reyrolle 415-volt 31·5-MVA air-break circuit-breakers of the type illustrated.



17-panel switchboard comprising Reyrolle type-S22A air-break circuit-breakers with associated control cubicles.

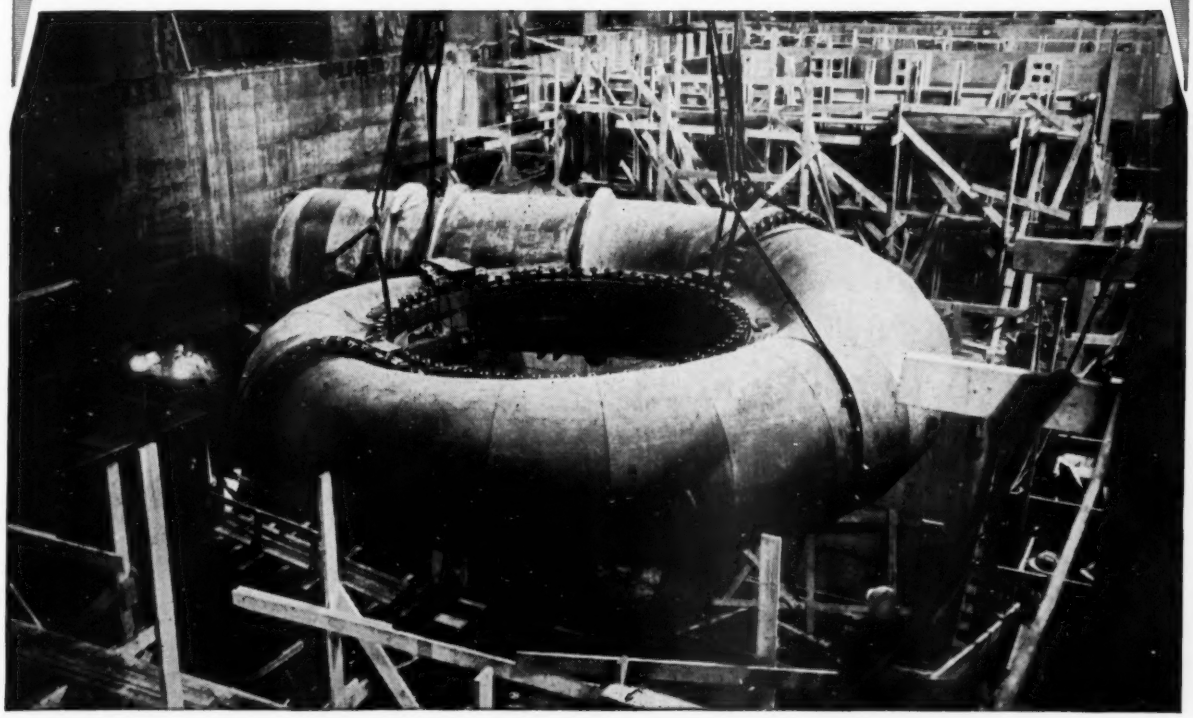
In addition, all five sub-stations of the main 11-kV distribution ring-main are equipped with Reyrolle metalclad switchboards with 350-MVA horizontal draw-out oil-break circuit-breakers.

Reyrolle

A. Reyrolle & Co. Ltd · Hebburn · County Durham · England

AT BERSIMIS

World's largest high head turbines



RECORD OUTPUTS OF 200,000 h.p. DEVELOPED

At Hydro Quebec's Bersimis-Lac Casse Development in Canada, four 'ENGLISH ELECTRIC' water turbines have regularly supplied 520,000 kW to Quebec's power system from one of the world's most powerful hydro-electric stations. On occasions 200,000 h.p. has been developed from a single turbine under a net head of 840 feet. This establishes a world record for hydro-electric units, being more than 10% greater than the output of any other high head turbine. These turbines of 'ENGLISH ELECTRIC' design were supplied by English Electric Company of Canada Limited, and were manufactured at the John Inglis Co. Limited plants in Toronto.

'ENGLISH ELECTRIC'
water turbines

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WATER SUPPLY
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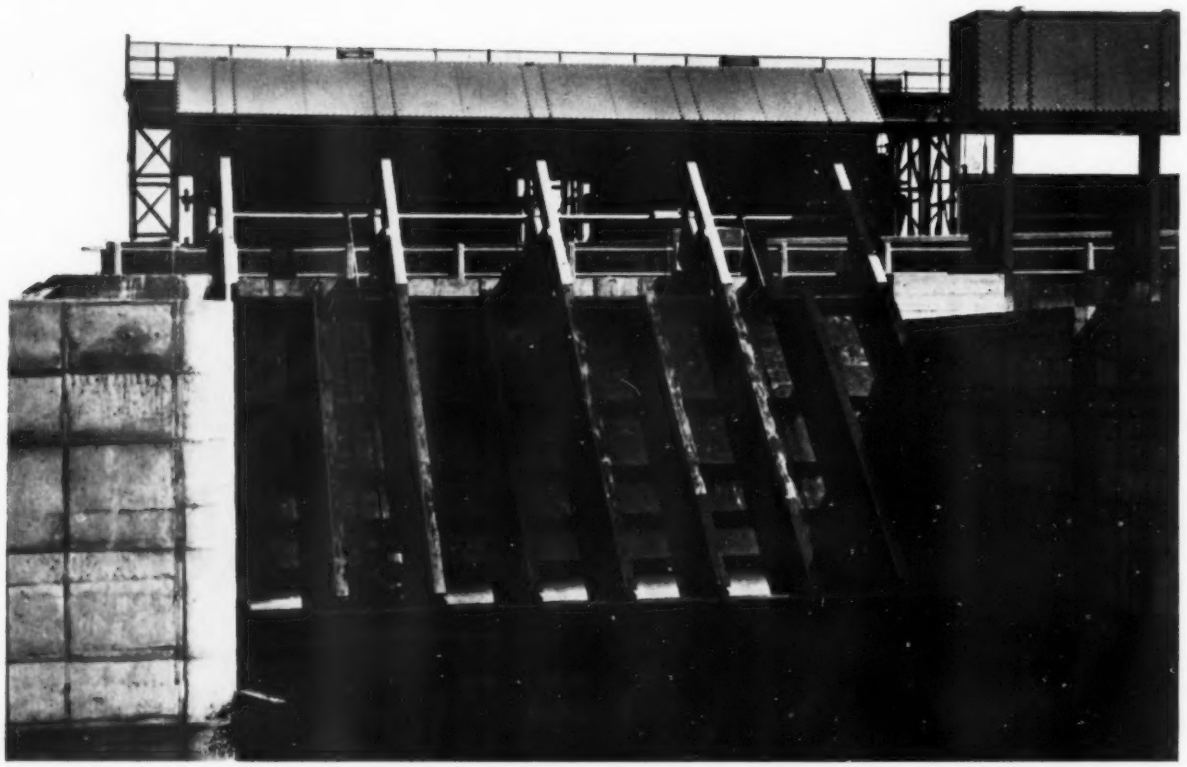
RapieR Sluice Gates are at both ends of the Spalding Flood Relief Channel, River Welland. Illustration shows one of the three tidal flap gates at the Marsh Road end. Each gate is 30 feet span by 18 feet deep to pass flood waters and prevent tidal waters entering the channel.

Three RapieR wheel gates, each 30 feet span by 19 feet deep are at the Cowbit Road end of the channel.

REMEMBER POPPY DAY



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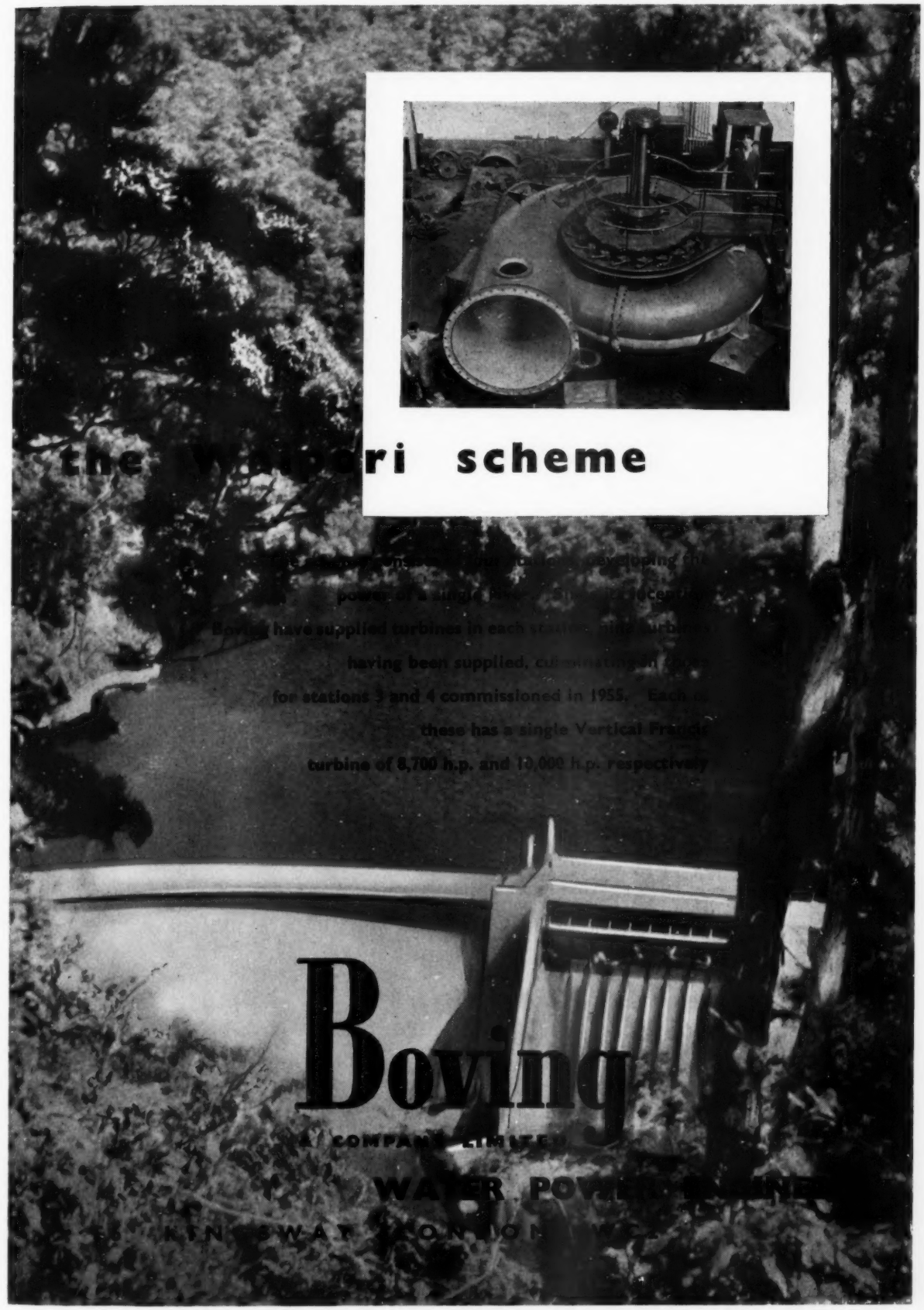
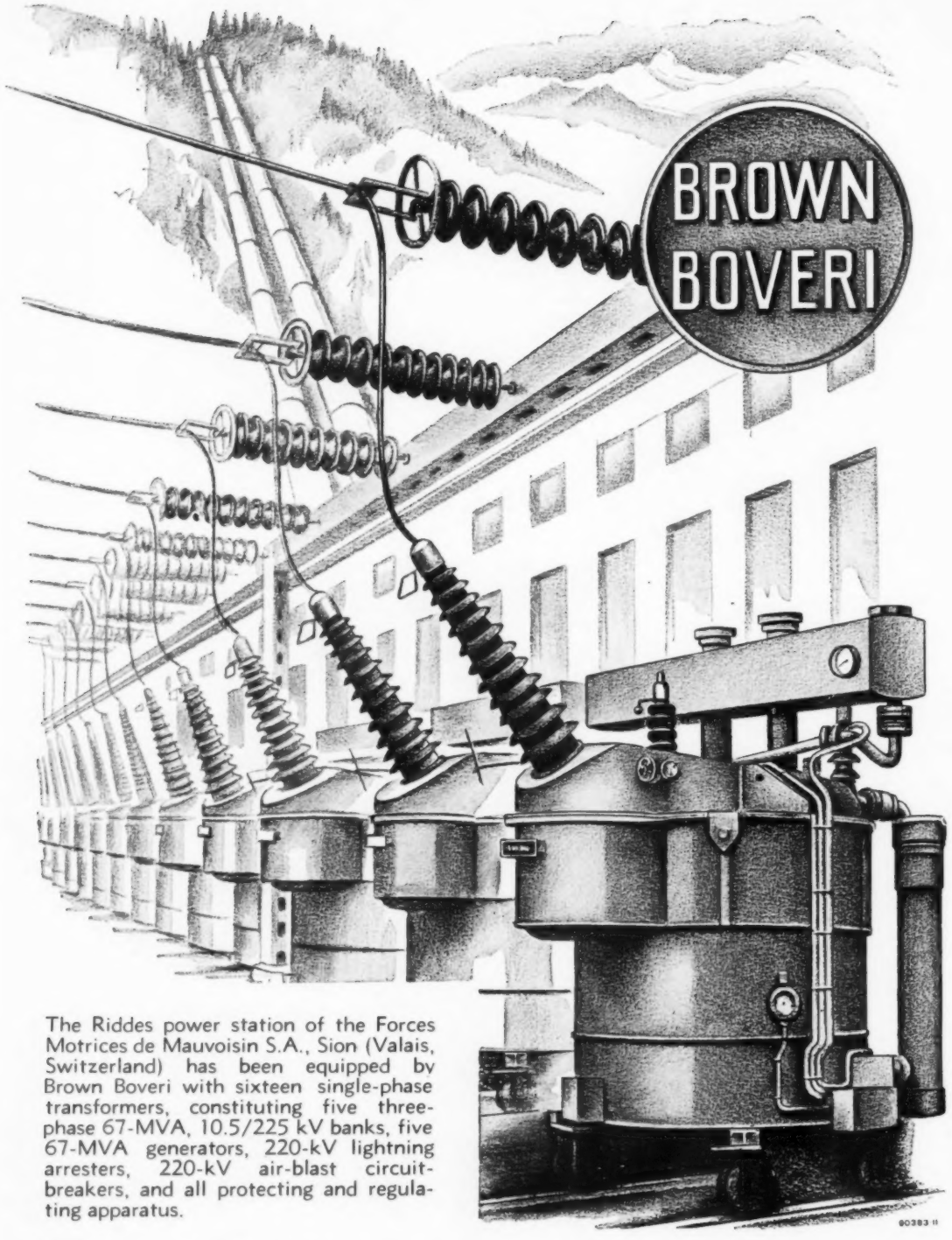

ri scheme
Boving
WATER POWER



The Riddes power station of the Forces Motrices de Mauvoisin S.A., Sion (Valais, Switzerland) has been equipped by Brown Boveri with sixteen single-phase transformers, constituting five three-phase 67-MVA, 10.5/225 kV banks, five 67-MVA generators, 220-kV lightning arresters, 220-kV air-blast circuit-breakers, and all protecting and regulating apparatus.

Transformers

built by Brown Boveri in single- and three-phase designs for voltages up to 400 kV and outputs up to 660 MVA are the result of unremitting research and co-ordinated teamwork. The Company's specialists will be glad to advise you.

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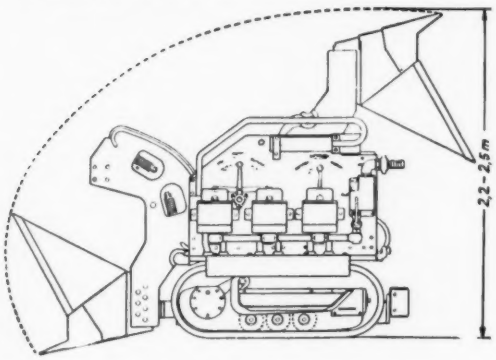

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The casting in the illustration is just one example of the work carried out by Birkett, Billington & Newton Ltd. Only the most modern equipment, combined with a high degree of skill and teamwork make it possible to produce such castings. These qualities have given Birkett, Billington & Newton a reputation for technical supremacy which extends throughout British industry. These qualities can solve *your* casting problems.

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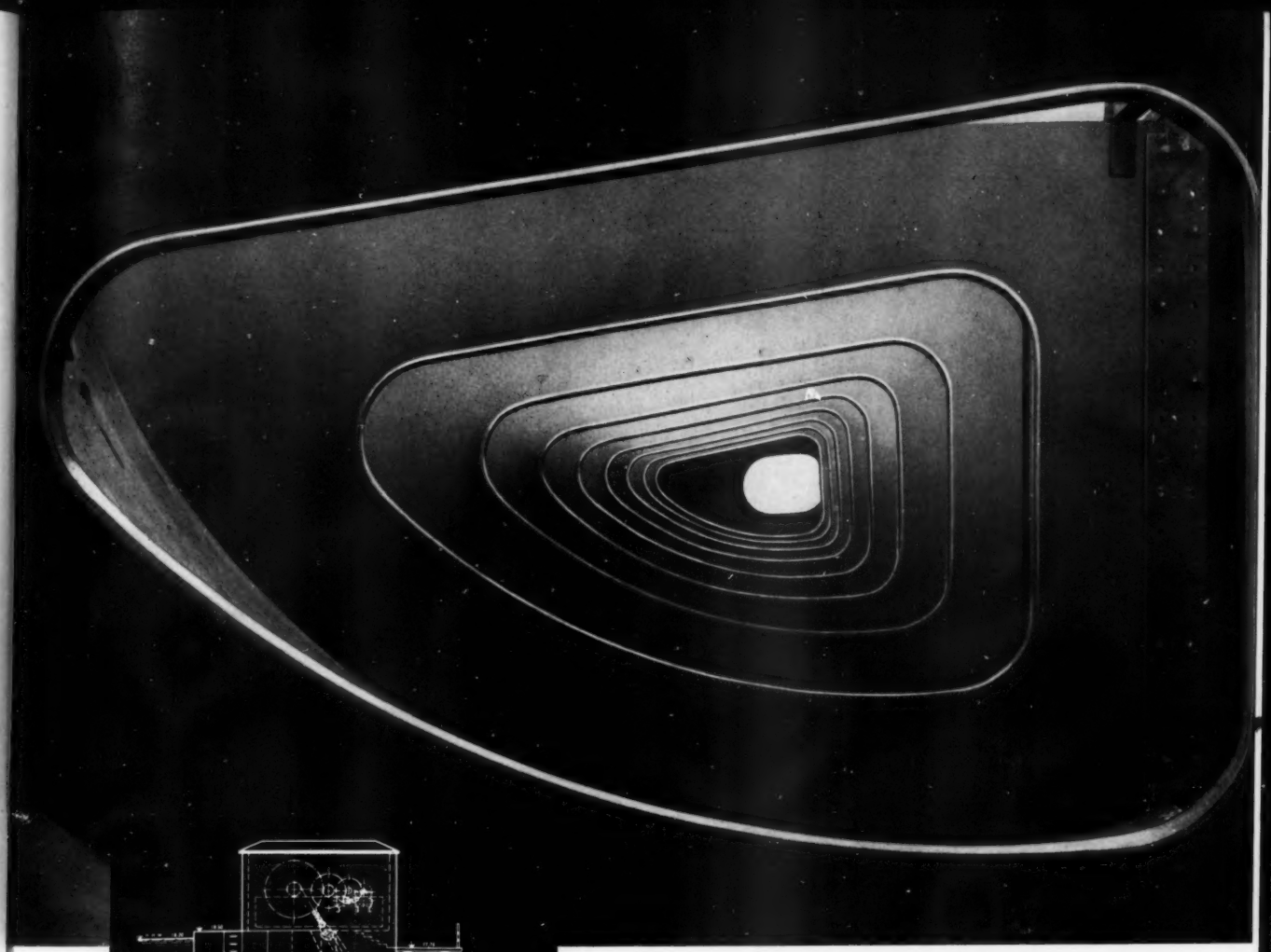

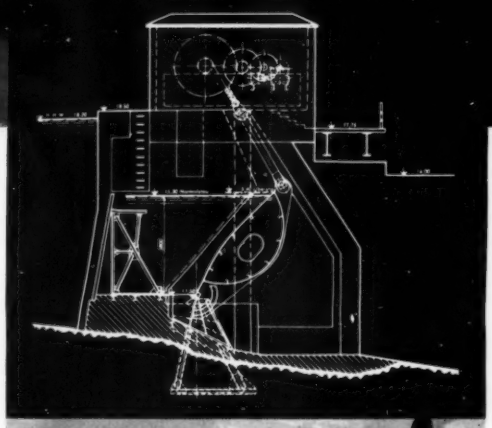

Above: Fishbelly flap, inside view
Centre: Section of a weir with fishbelly flap
Below: Fishbelly flap, 24.5 m. width, 3.8 m. high, assembled in the workshop

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CALIFORNIA-OREGON POWER COMPANY...

another 100% Dresser-Coupled penstock

Two views of Yamsay, Oregon, uncovered penstock of California-Oregon Power Company. This is a 100% Dresser-Coupled line...3847 ft. long, 55 ft. sections, from 126-in. diameter at inlet to 88-in. at outlet. Wall thickness varies from ¼ inch plate to 1-7/16 inch.

Each Dresser Coupling is engineered to meet the pressure at each portion of the penstock

Near Yamsay, Oregon, you'll find another impressive argument for using steel-pipe penstocks and Dresser Couplings. This penstock (described above) is owned by The California-Oregon Power Company, was engineered by Pioneer Service and Engineering Co. The line is 100 percent Dresser-Coupled...the only type of joint which could be individually tailored to the pressure requirements at each portion of the penstock.

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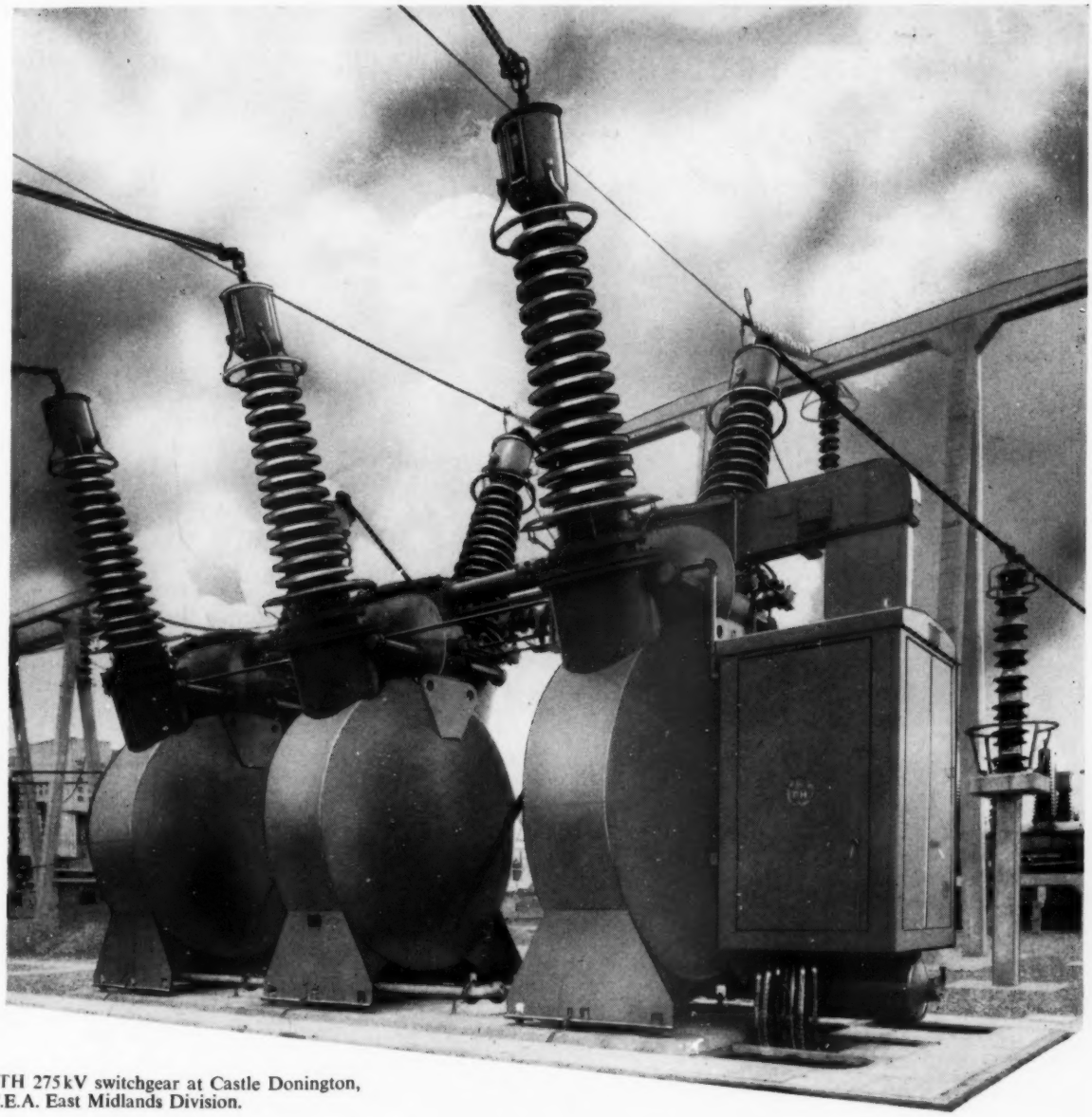

BTH 275kV switchgear at Castle Donington,
C.E.A. East Midlands Division.

B T-H

330-kV SWITCHGEAR
for
KARIBA

The two million pound order awarded to British Thomson-Houston for the Kariba Hydro-electric Scheme includes 23 oil circuit-breakers of the BTH lenticular type. These units are a direct development of those installed on the 275kV British Super-Grid.

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WHEN THE PROBLEM SEEMS UNSURMOUNTABLE

Bailey Bridges the gap

Courtesy of: R. M. Finch Esq., City Engineer, Nottingham, R. Travers Morgan & Partners and James Miller & Partners Limited

. . . By-pass Roadways and Bridges, Dam Construction, Gantries, Scaffolding and Falsework, are typical uses for Bailey Bridging. Illustrated opposite is a traversing Bailey Gantry used to position concrete beams on the Clifton Bridge, Nottingham.

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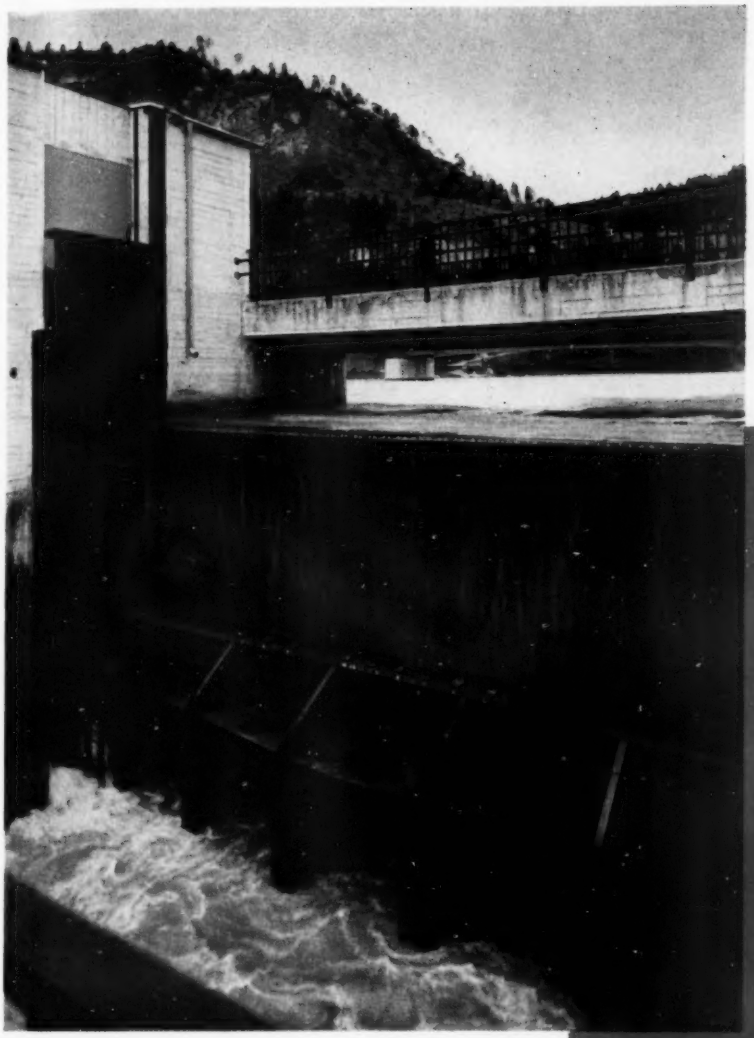
M·A·N



HYDRAULIC STRUCTURES

M·A·N hook-type gates enable, besides fine regulation by lowering the top gate by approx. 40% of the total retaining height, the discharge of average floodwater without operating the bottom gate. Füssen/Lech Weir Plant with 3 M·A·N hook-type gates of 10.5 m clear width and 9.0 m retaining height each.

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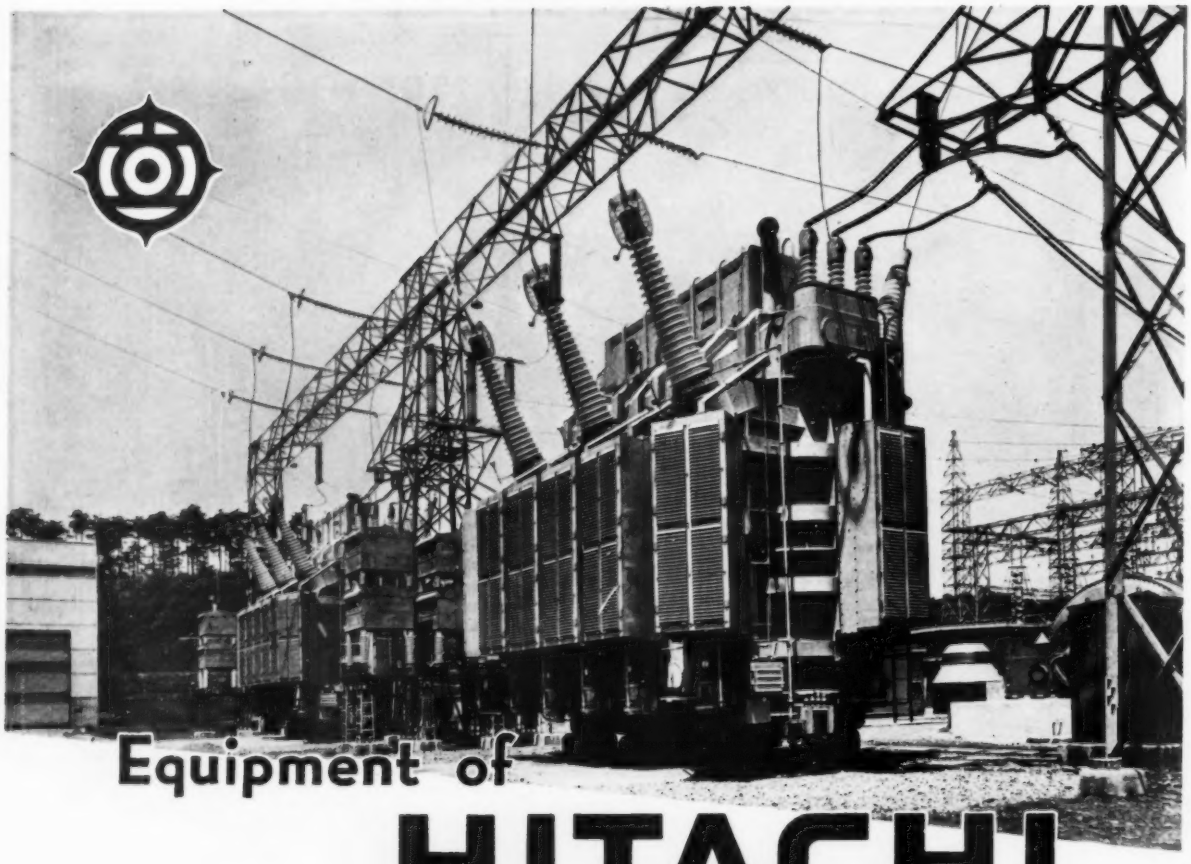

Equipment of HITACHI

for Substation Service

The photo shows Hitachi's 156,000 kVA super high-voltage transformers in service at the Nishi Tokyo Substation of the Electric Power Development Co. These outdoor type transformers are of 3-phase, 3-winding, core-type, forced oil and air-cooled system. The high and medium voltage winding of these transformers is provided with a Hitachi patent contro-surge winding to increase their series electrostatic capacity and improve impulse voltage characteristics.

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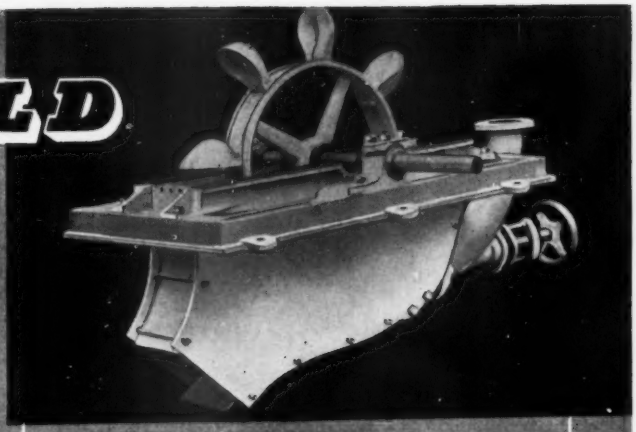
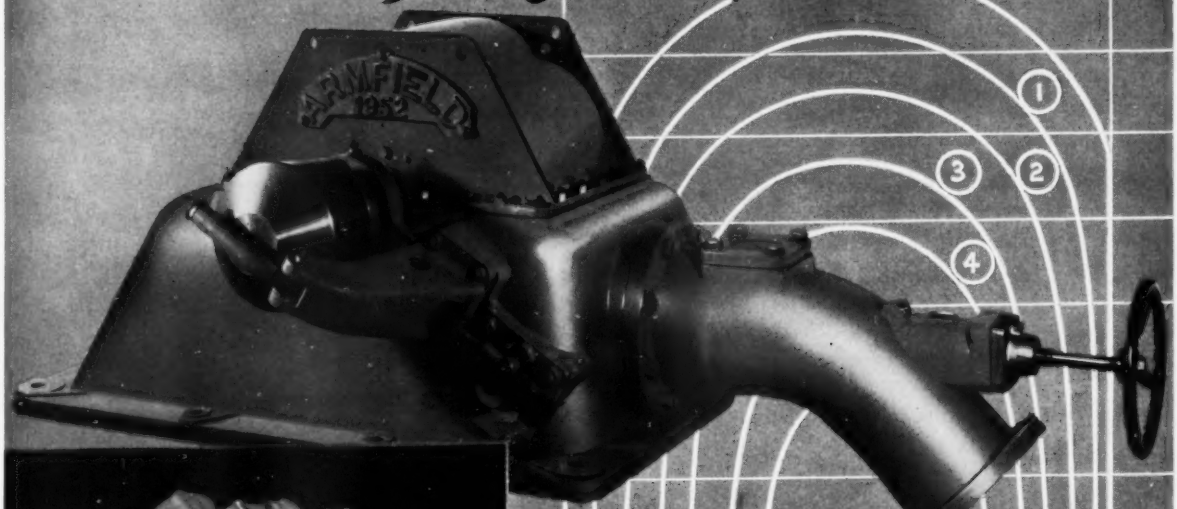
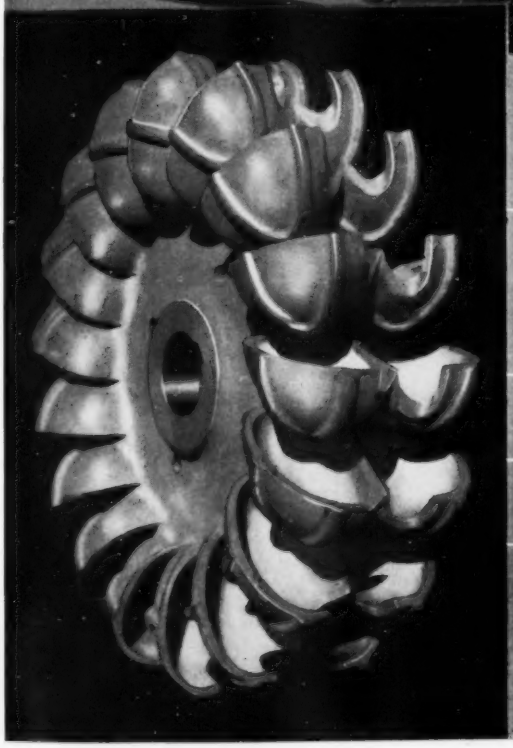


Are backed by 60 years of development





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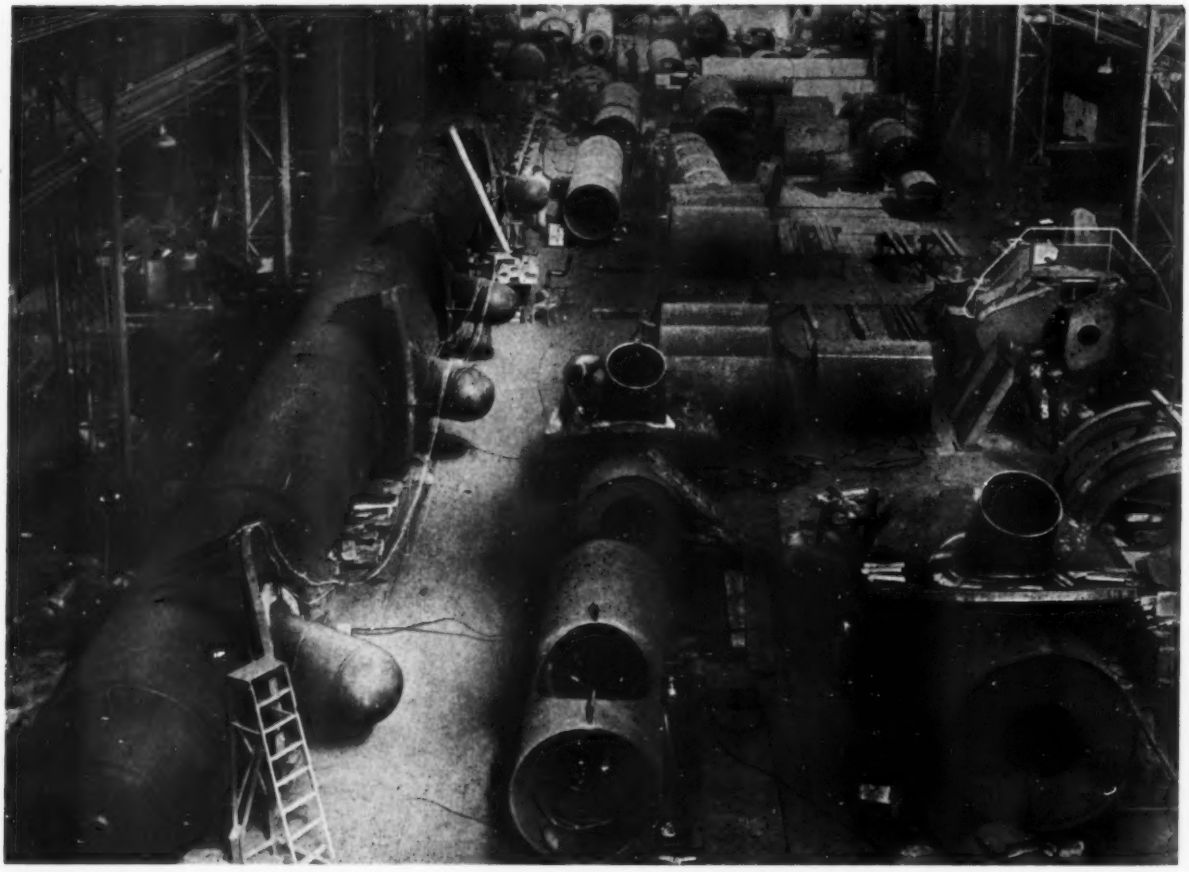

Downstream portion of the Grande Dixence Fionnay Power Station distribution pipe during tensometric shop tests. Max. wall thickness 52 mm., service pressure 96 at., test pressure 121 at.

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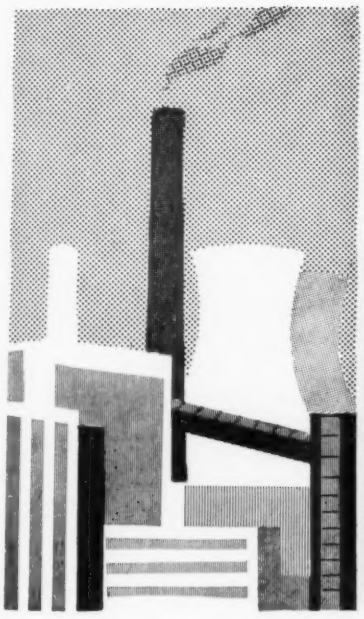
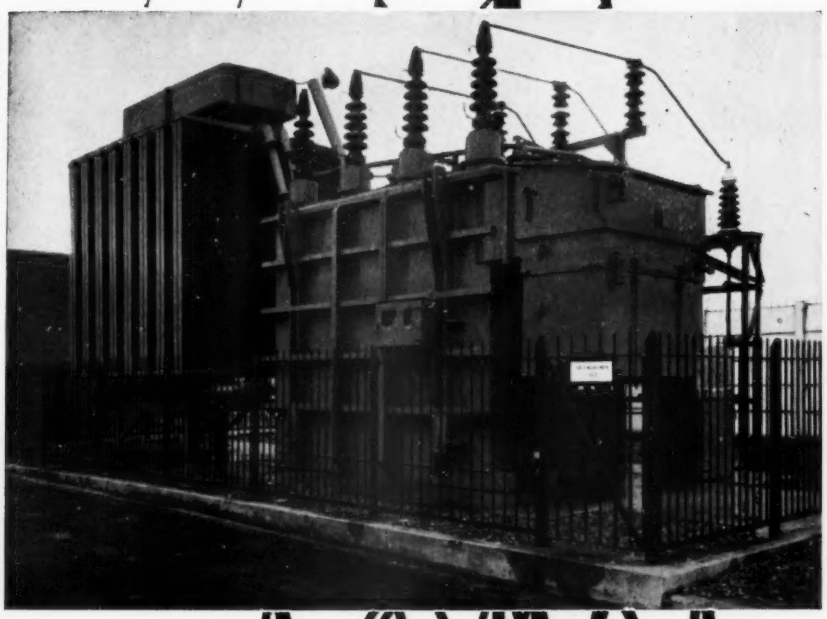
YORKSHIRE *transformers*

serve the power supplies of Great Britain





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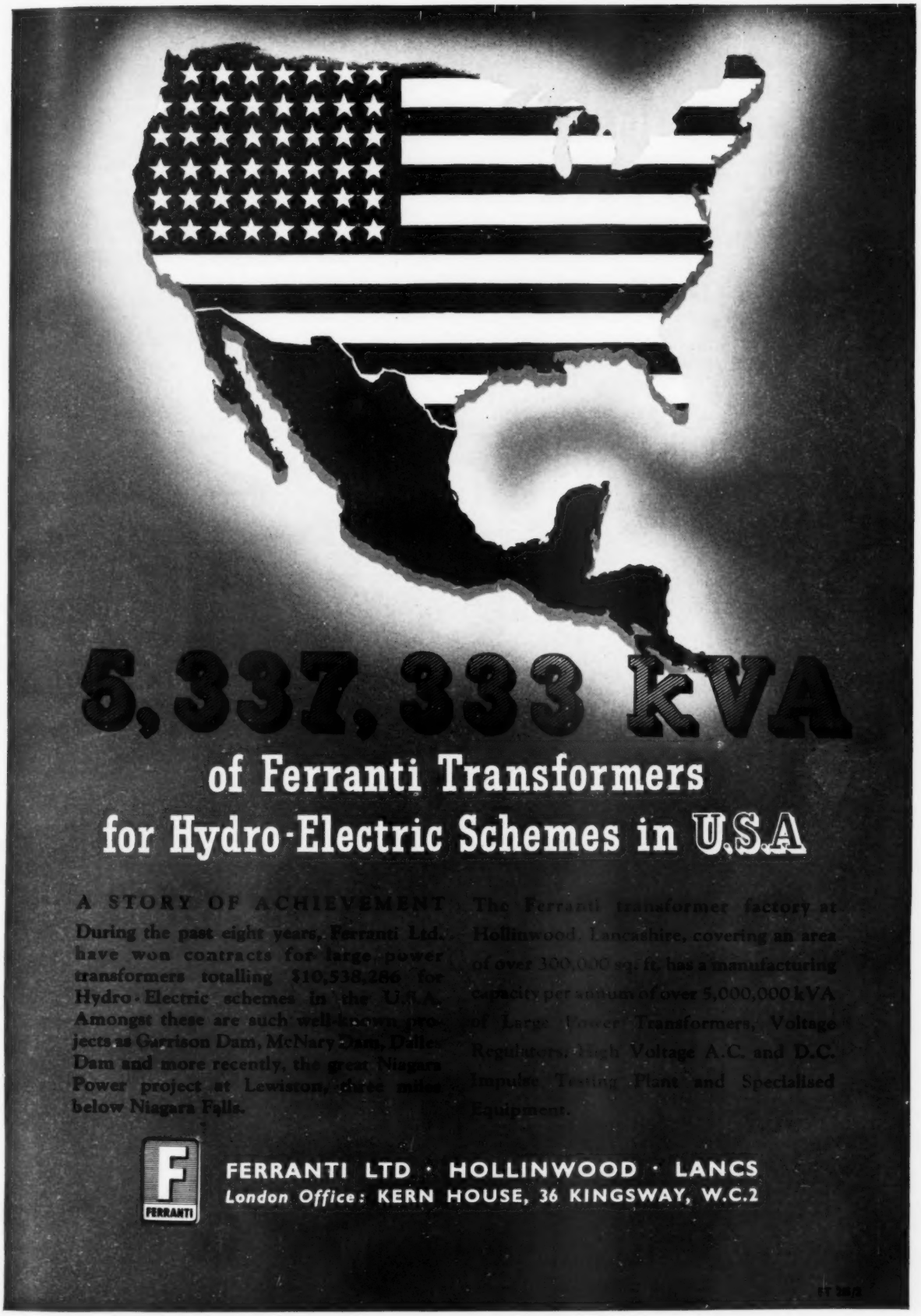
5,337,333 kVA
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for Hydro-Electric Schemes in U.S.A
A STORY OF ACHIEVEMENT
During the past eight years, Ferranti Ltd. have won contracts for large power transformers totalling $10,538,280 for Hydro-Electric schemes in the U.S.A. Amongst these are such well-known projects as Garrison Dam, McNary Dam, Dalles Dam and more recently, the great Niagara Power project at Lewiston, three miles below Niagara Falls.
The Ferranti transformer factory at Hollinwood, Lancashire, covering an area of over 300,000 sq. ft. has a manufacturing capacity per annum of over 5,000,000 kVA of Large Power Transformers, Voltage Regulators, High Voltage A.C. and D.C. Impulse Testing Plant and Specialised Equipment.
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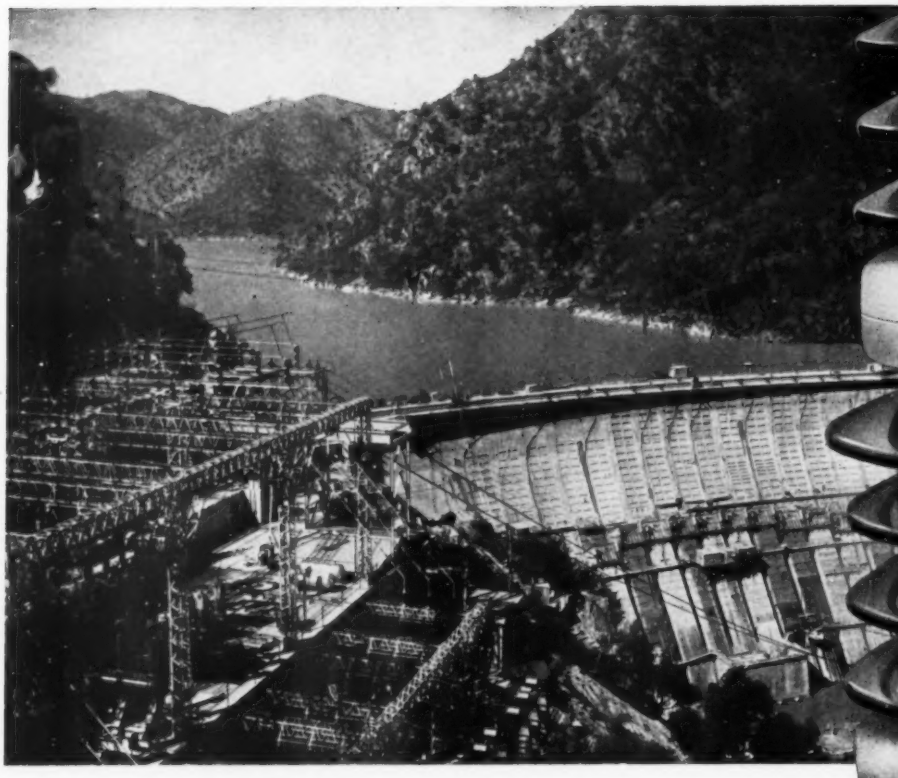
S.P.P. Post Insulators were used for the New South Wales Public Works Department for Burrinjuck Sub-Station.



The Burrinjuck 132 kV Switching Station was equipped with Cylindrical Post Insulators type P.703. This is one of many stations on the New South Wales Public Works Department system equipped throughout with S.P.P. Post Insulators for 110 kV and 66 kV.

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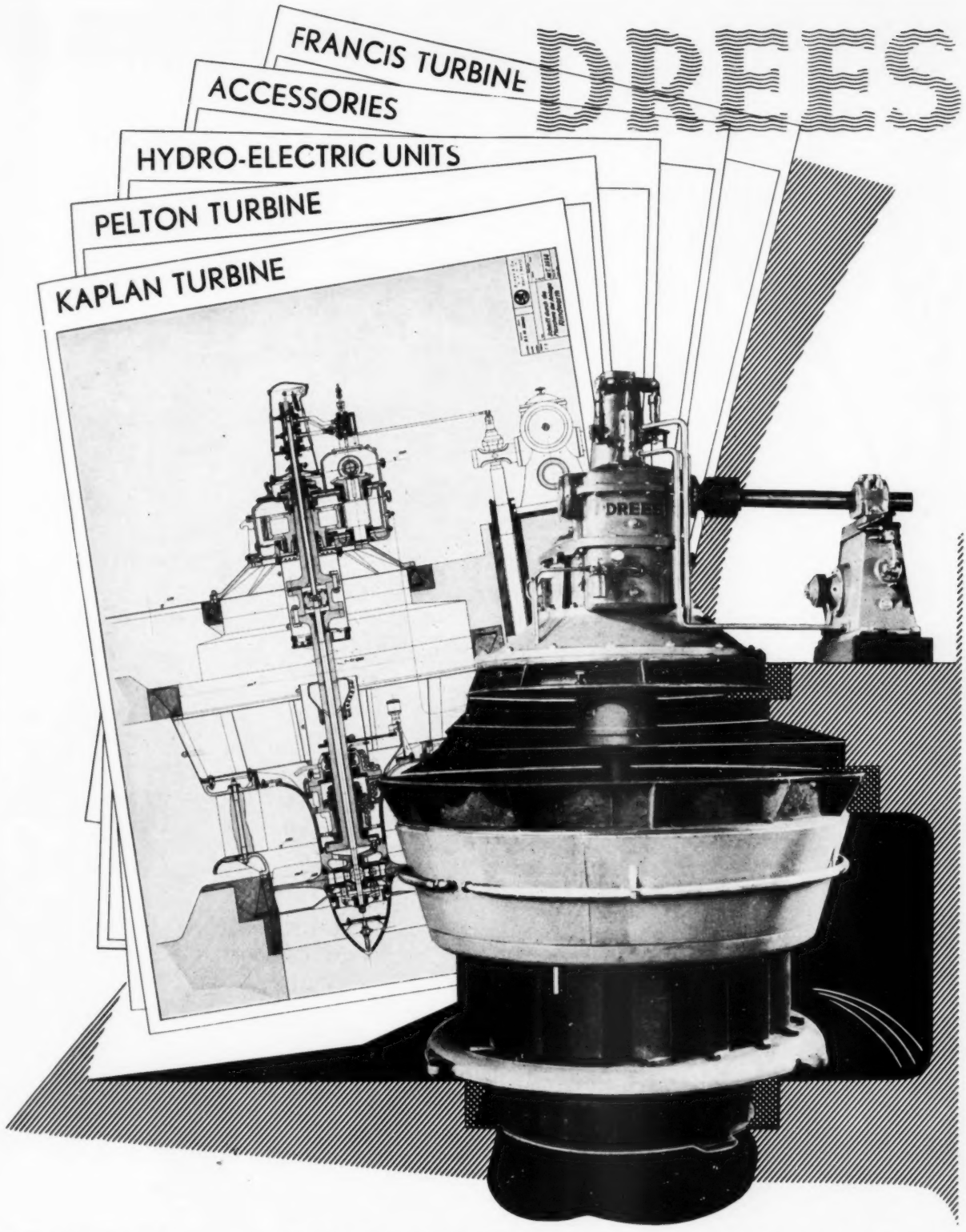

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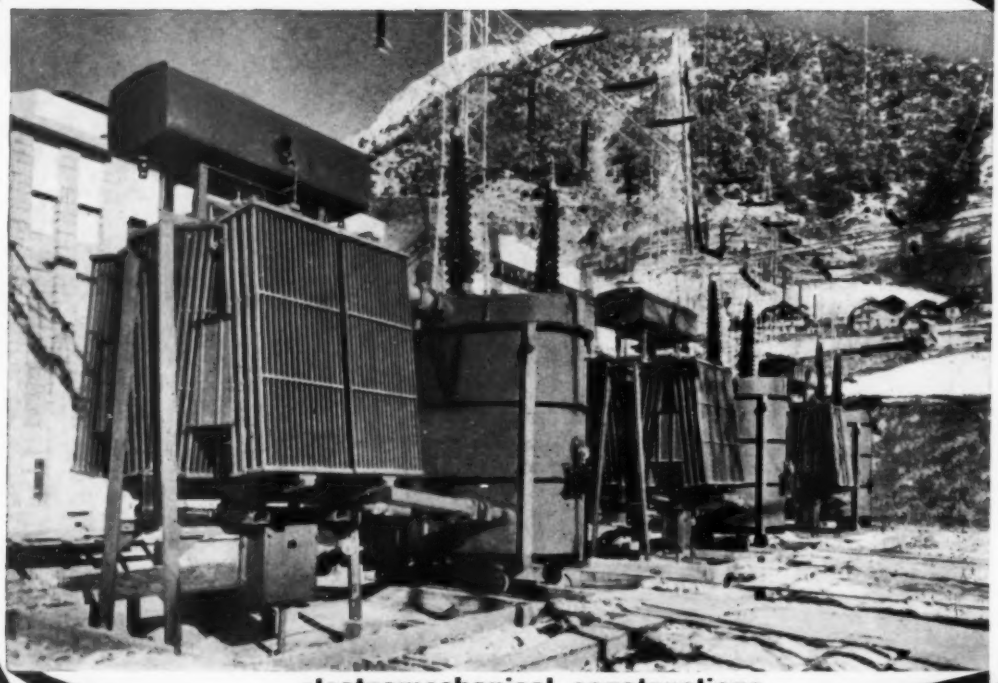
savigliano



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corso mortara 4
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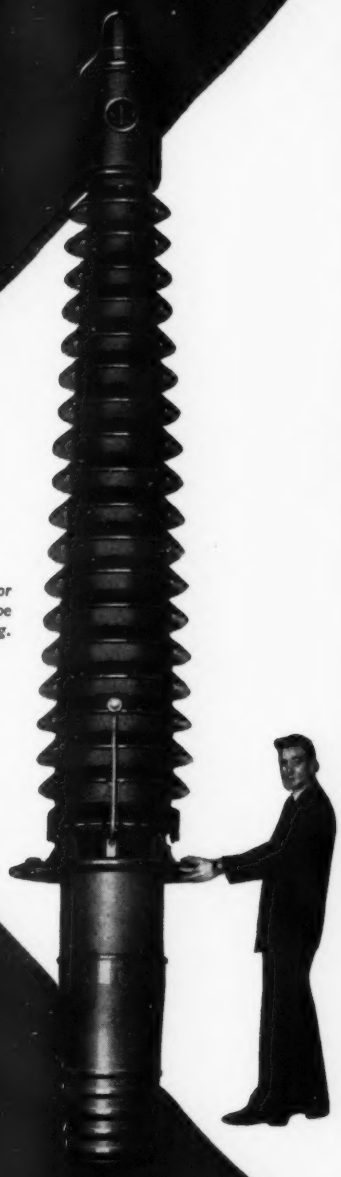
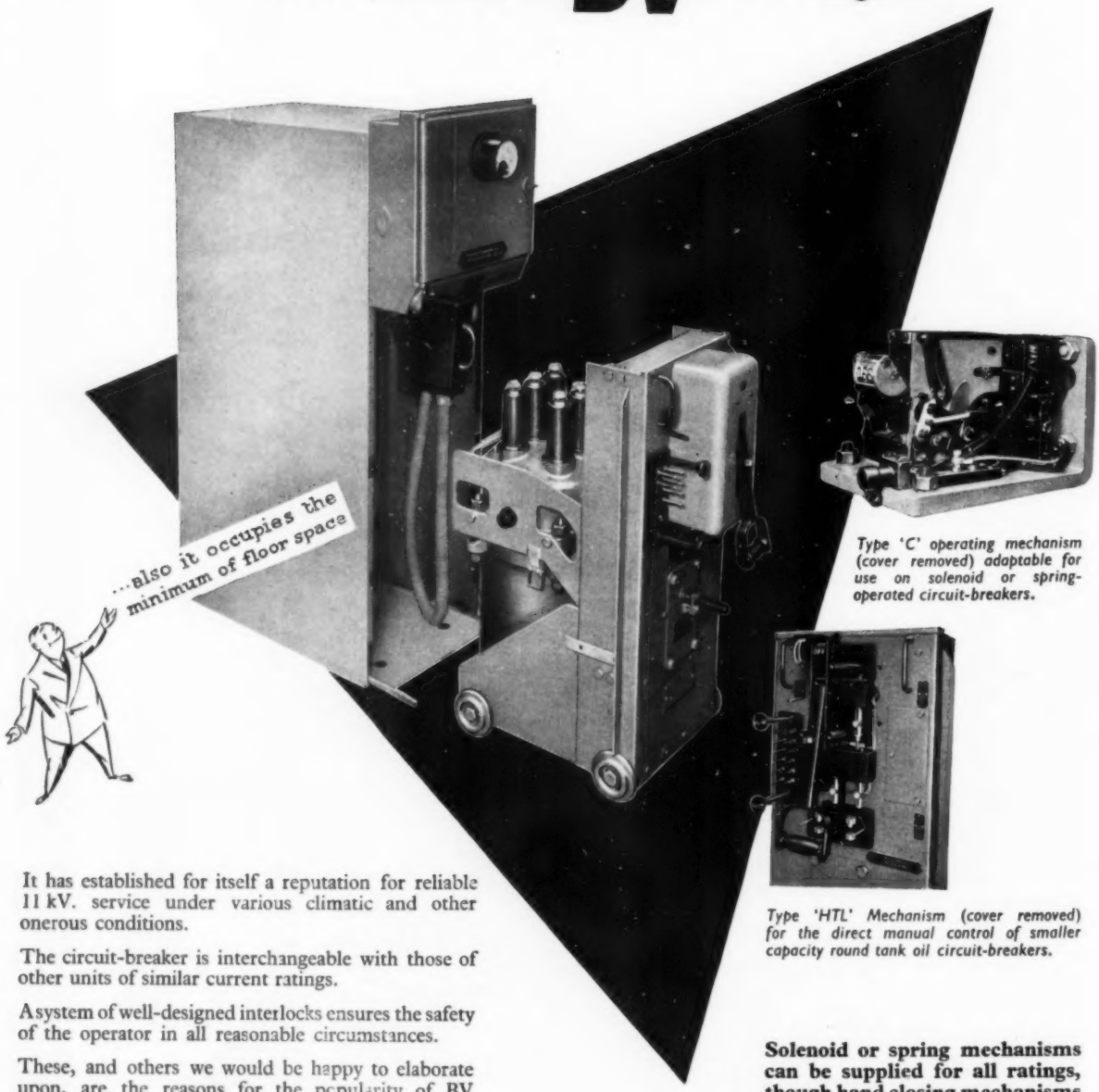
We go from one extreme to the other



A 400 kV outdoor re-entrant type transformer bushing.

m and i the electrical insulation people

Reasons for the popularity of air insulated **BV** Switchgear



Type 'C' operating mechanism (cover removed) adaptable for use on solenoid or spring-operated circuit-breakers.

Type 'HTL' Mechanism (cover removed) for the direct manual control of smaller capacity round tank oil circuit-breakers.

It has established for itself a reputation for reliable 11 kV. service under various climatic and other onerous conditions.

The circuit-breaker is interchangeable with those of other units of similar current ratings.

A system of well-designed interlocks ensures the safety of the operator in all reasonable circumstances.

These, and others we would be happy to elaborate upon, are the reasons for the popularity of BV Switchgear, which may be found in service in all parts of the World.

Solenoid or spring mechanisms can be supplied for all ratings, though hand closing mechanisms are normally supplied up to a rating of 150 MVA.

NORMAL APPLICATION: Up to **800 A, 11 kV, 75/250 MVA** **SINGLE BUSBAR SYSTEMS**

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VOITH

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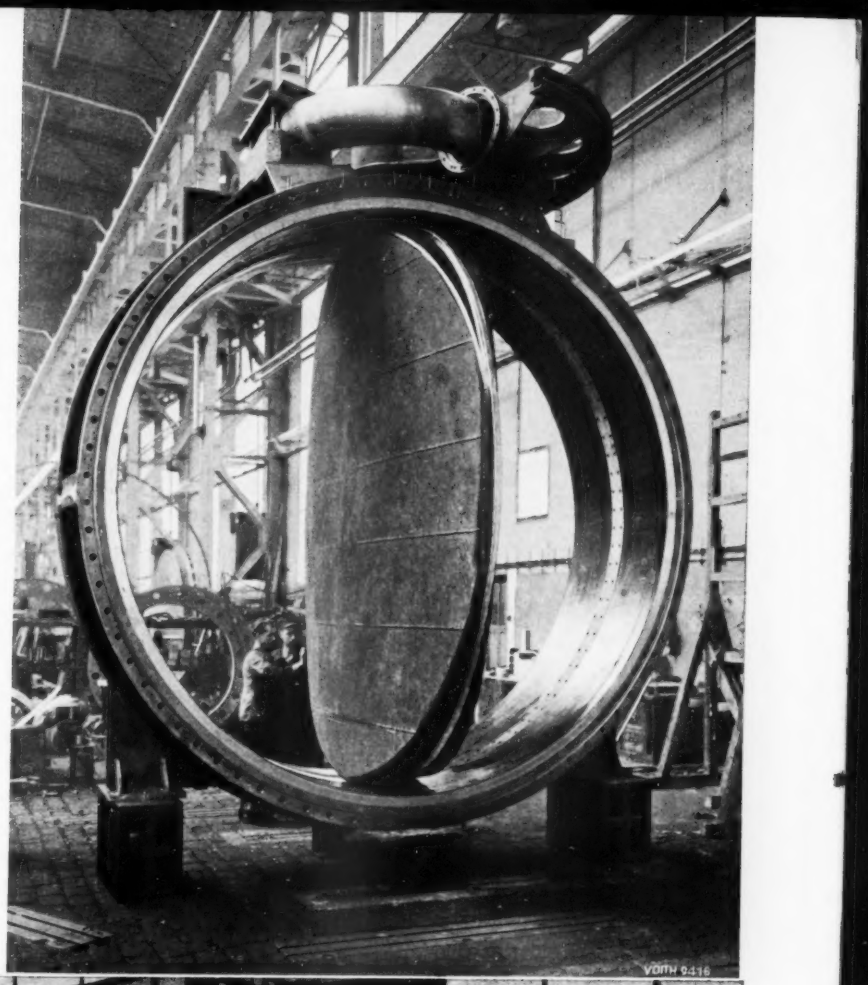
For the successful and dependable operation of hydro-electric power plants

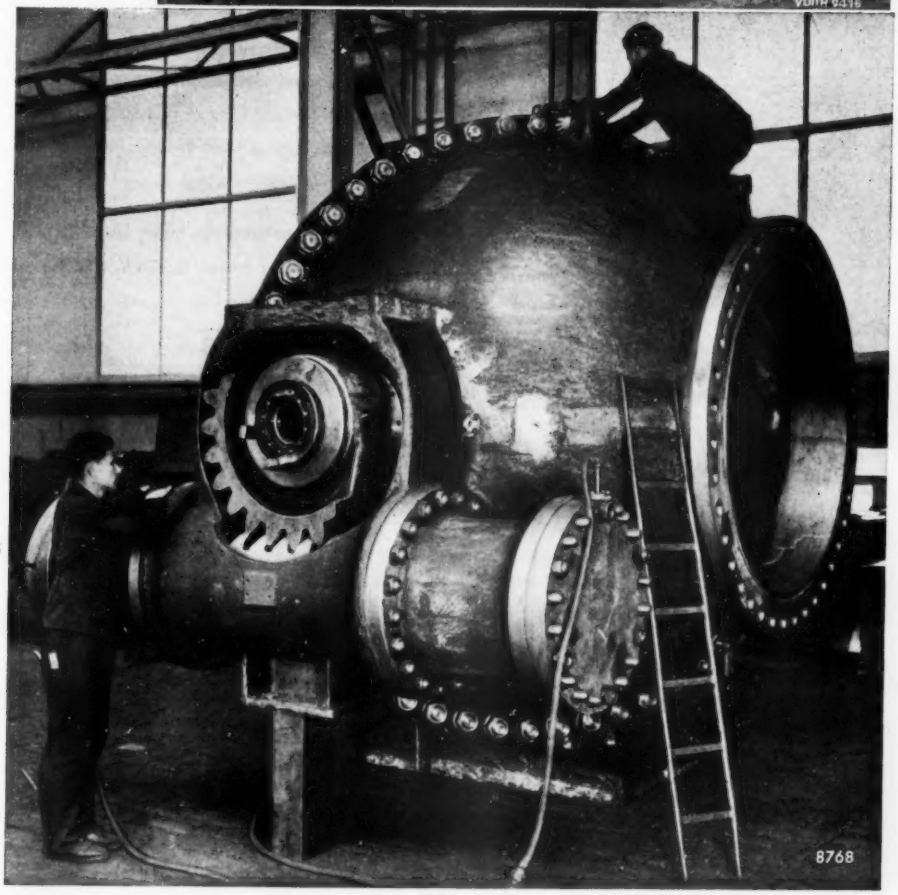
SHUT-OFF VALVES

are no less essential than water turbines

(top) One of three 12ft. 6in. dia. all-welded weight-actuated butterfly valves for installation at the beginning of the penstocks of the Geesthacht Pumped Storage Plant near Hamburg, which is equipped with another three Voith butterfly valves of the same physical size to shut off the water flow to the turbines.

(bottom) 5ft. 6in. dia. Voith rotary valve as used ahead of the turbines in the Reisach-Rabenleite Pumped Storage Plant (Bavaria).





Water has its uses . . .

COMMON FROG

Found abundantly all over the British Isles, Rana temporaria, the common frog, feeds on insects, worms, slugs etc., taking its food mainly at night. Frogs breed as soon as they emerge from their winter hibernation and then leave the water, living in damp places on land. In coloration, the common frog is most variable and may be grey, olive, brown yellow or red above, with darker spots and markings.

The placid pools, lakes and slow-moving streams beloved by frogs provide water for larger rivers that in turn can become one of man's chief sources of power.

Wherever there is falling water a water turbine can be installed—the simplest and most reliable form of prime mover—no fuel bills, long life, little maintenance and requiring only unskilled attention.

GILKES are specialists in the field of small hydro-electric units; we can supply installations to operate on any head from 3 feet to 5,000 feet (or 1 metre to 1,500 metres) and to develop any output up to 1,000 kilowatts on low heads or 10,000 kilowatts on the higher heads.

If you wish to make the fullest and most economic use of your potential water power, let GILKES advise you.

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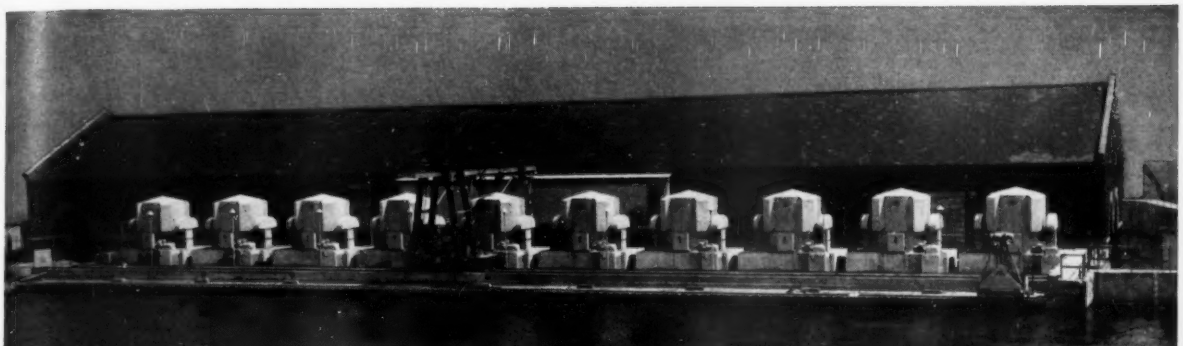
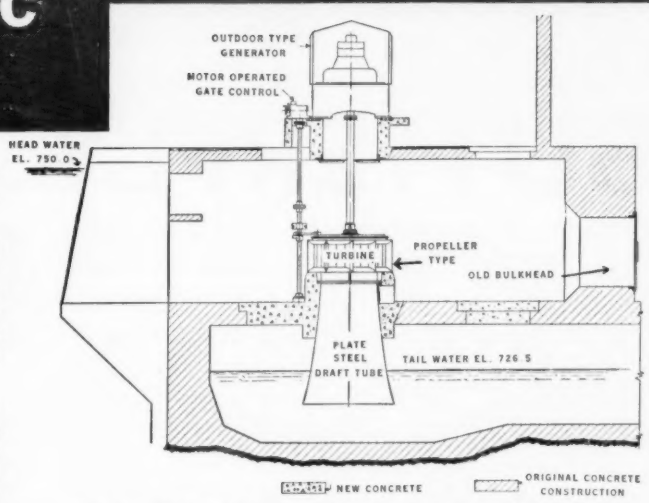


TEN LEFFEL TURBINES POWER THIS UNIQUE, OUTDOOR HYDROELECTRIC PLANT



Each of the 10 Leffel hydraulic turbines in the Lower Dam Hydro Plant is rated to develop 1160 H. P. under 23.5 Ft. net head, speed 225 R.P.M.

Another installation of efficient Leffel turbines is at the Lower Dam Hydro Plant, St. Anthony Falls, of the Northern States Power Company.

This plant is located a half-mile below the Falls of St. Anthony on the Mississippi River at Minneapolis, Minnesota. It was reconstructed in 1952 in cooperation with the Engineers Corps, Department of the Army's plan to extend the nine-foot navigation channel in the Mississippi River at Minneapolis.

The most feasible method for rehabilitation of the old plant was the installation of vertical, single runner units centered on the old multiple runner turbine settings outside the existing powerhouse. Unique steel housings, known as "Igloos", were used to protect the generator units from adverse weather conditions frequent in this upper Midwest area (Temperatures range from 105 to −30 degrees Fahrenheit).

By utilizing the existing structure in the rehabilitation of the Lower Dam Hydroelectric Plant, Northern States Power Company derived a modern, efficient plant at the lowest possible cost. Such savings are typical whenever and wherever efficient, creative engineering is put to work.

Leffel engineers have a full grasp of the theories and principles involved with *practical* hydroelectric power development such as this. And Leffel, with almost a century of experience, has the technical skill and production facilities necessary to produce turbines and related equipment of the highest quality, durability and efficiency.

If you're planning the rehabilitation or expansion of an out-dated plant, or the building of a new one, put Leffel technical ability and experience to work for you. There is no obligation.

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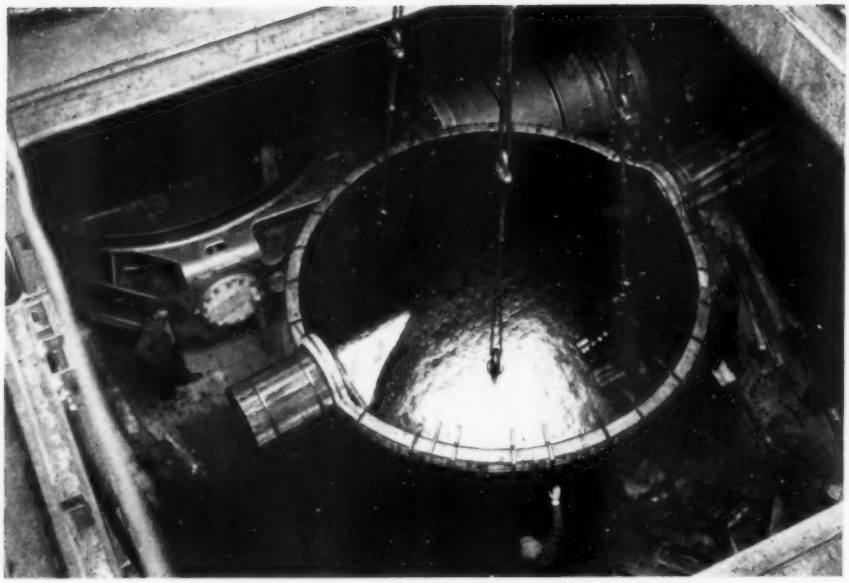
At the Power House



BUTTERFLY VALVES

Glenfield experience in the design and manufacture of Butterfly Valves for turbine isolation purposes, and also for portal and automatic cut-off services in pipelines, is that of the expert.

Valves of this type have been produced by us in many sizes for a wide range of operating conditions, for numerous important hydro-electric stations in various parts of the world, and have included the largest yet made in Britain.

Illustrated are two outstanding examples of large valves, the orders for which were placed with us by Boving & Co. Ltd., London. Above is shown the loading on board ship at Glasgow of parts of one of two 14 ft. 6 in. dia. hydraulically operated units for the Big Eildon Irrigation and Power Project, Victoria, Australia; and left, one of three similarly actuated 13 ft. dia. valves in Los Peares Station, Spain.

Valve Specialists and Hydraulic Engineers for over a century

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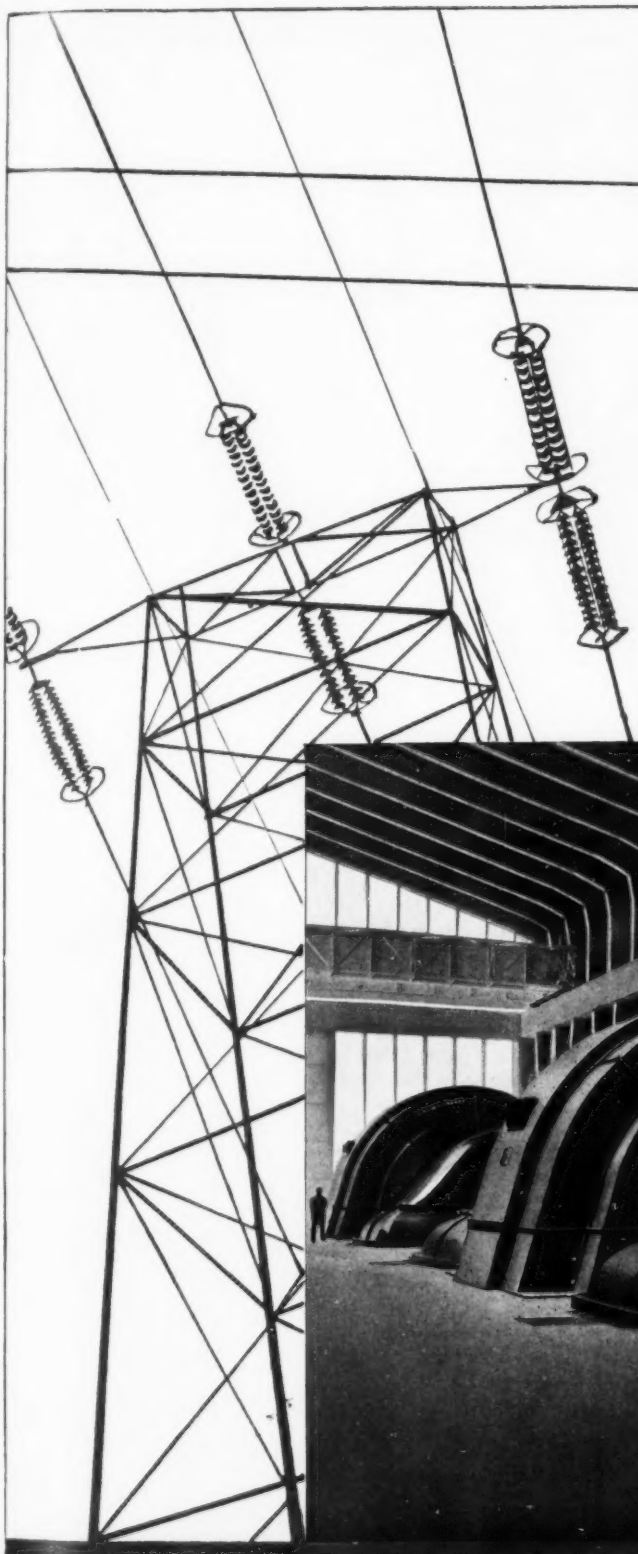

Soc. Idroelettrica Alto Chiese Cimego Hydro - Electric Power Station. Two 110,000 kVA horizontal shaft alternators 13,800 V. — 50 cycles — 300 r.p.m. — PD^2 4,400 tm^2 — each weighing 650 tons — coupled to 150,000 H.P. Pelton turbine.

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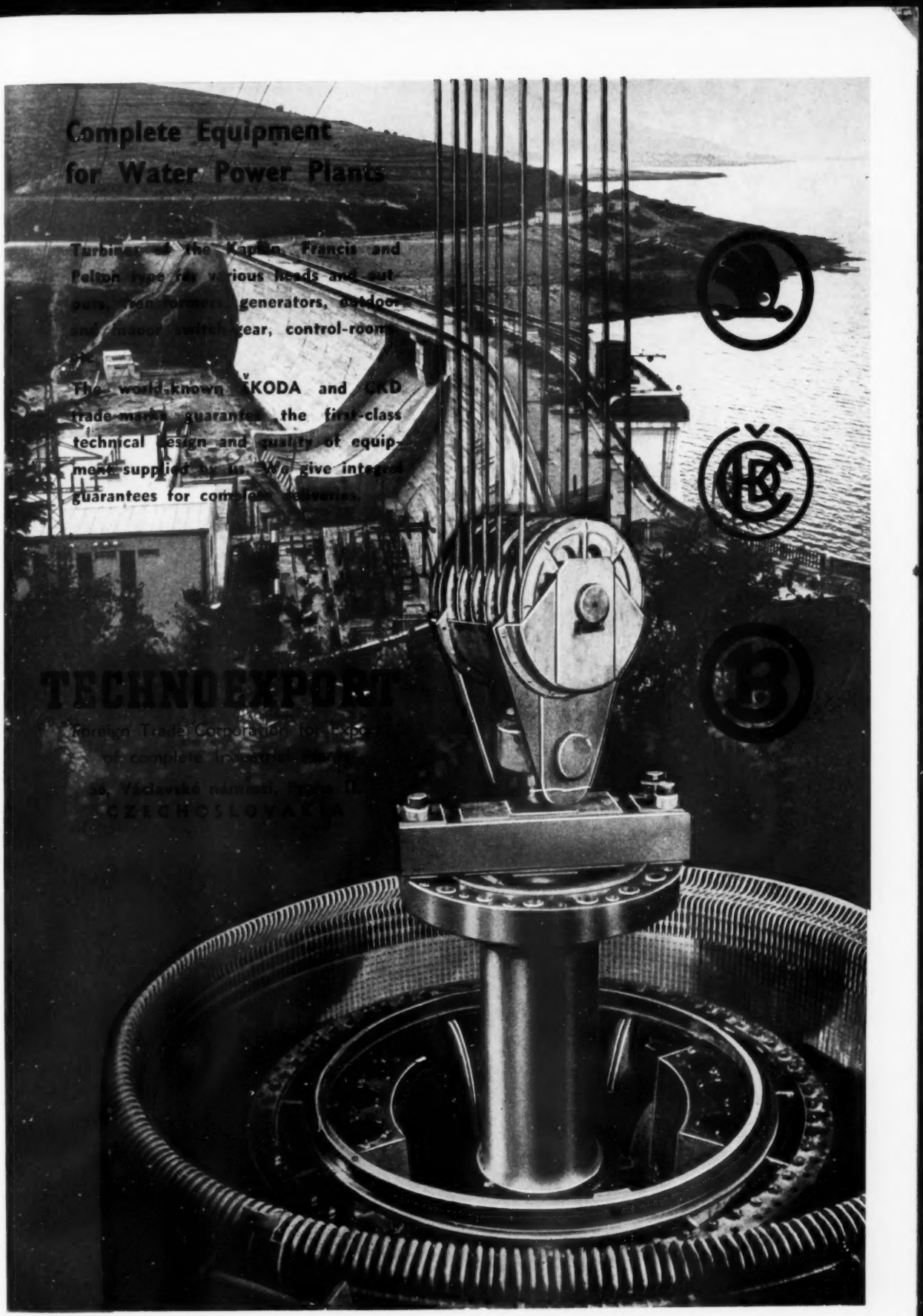
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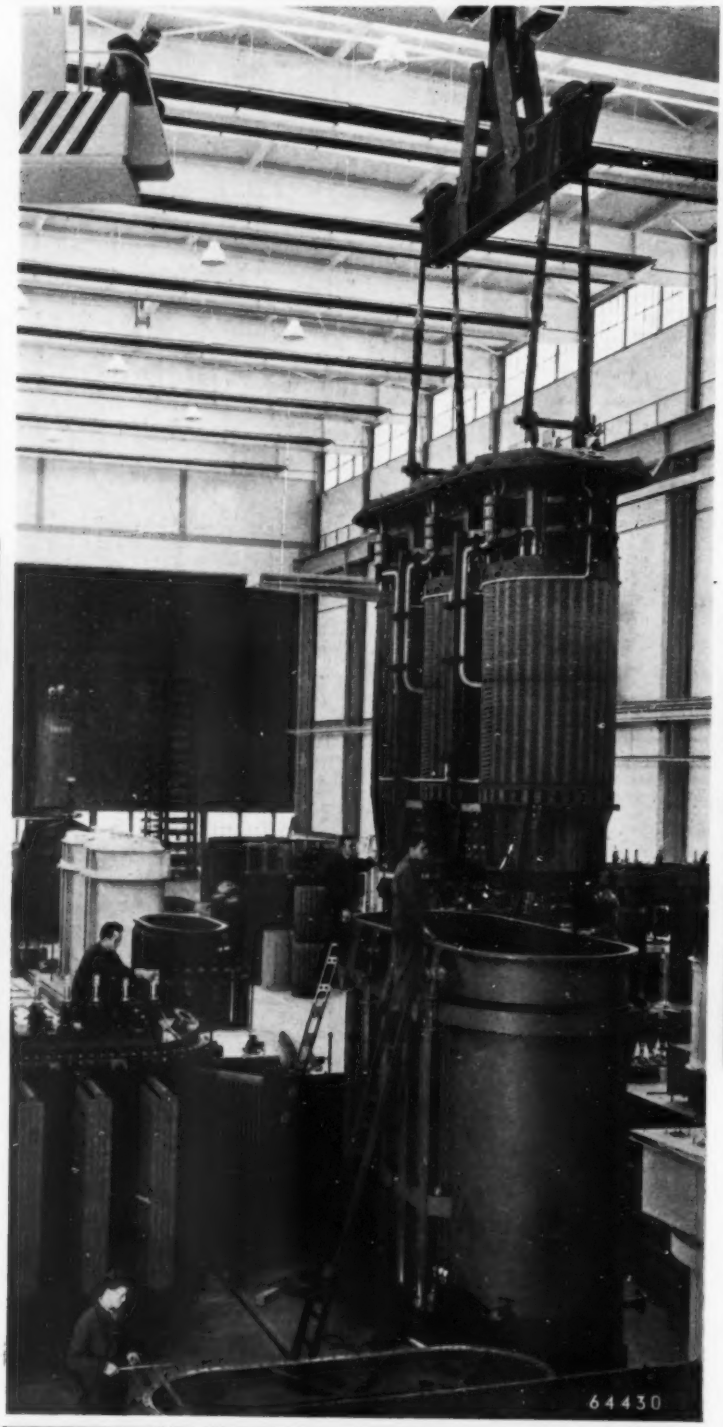

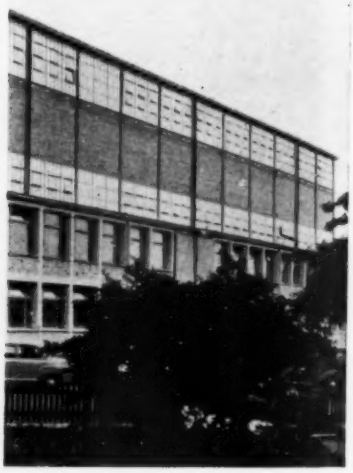

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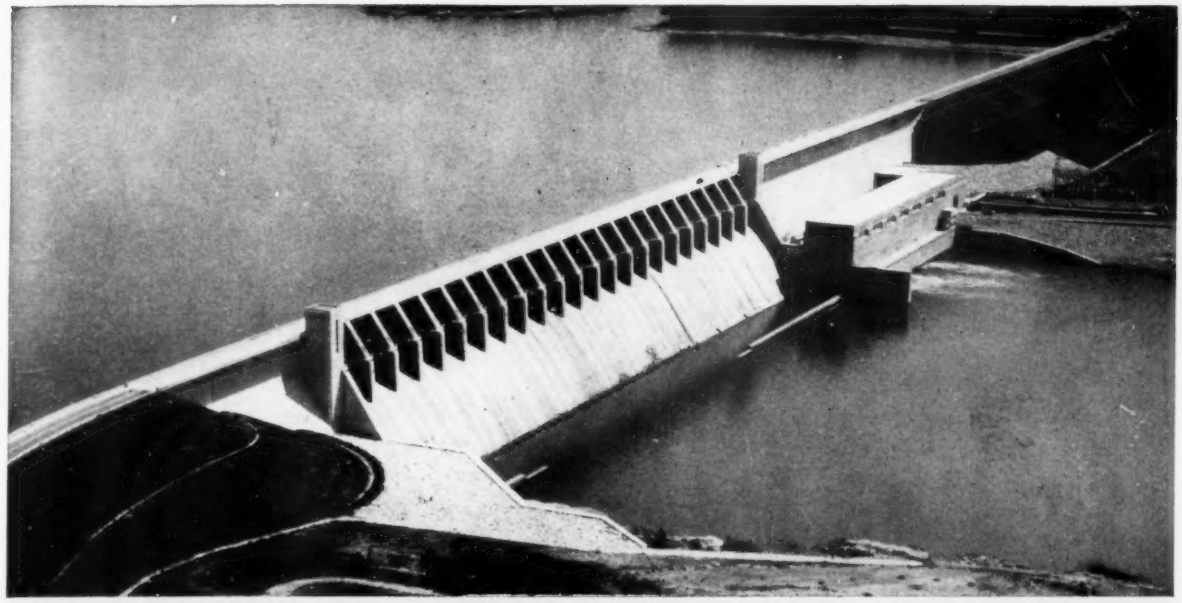

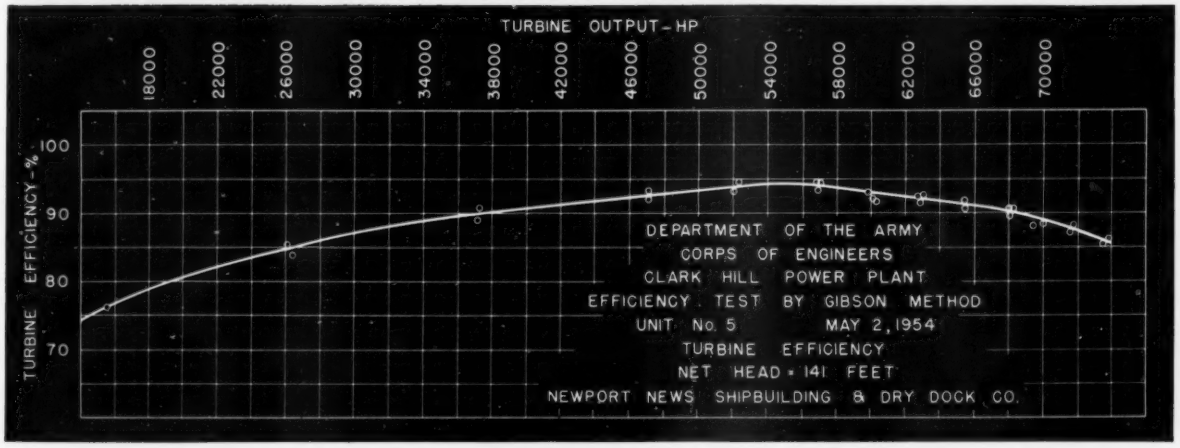

Maximum efficiency of 94.1%

Reflects advanced practices at Newport News

THE GRAPH shows performance of a 55,000 horsepower turbine, one of seven such units built by Newport News for the Clark Hill Power Plant (see photo).

Shape of the curve is typical . . . not exceptional . . . for Newport News turbine performance. Regular, uniform, showing no-cut-off at full load, it indicates consistent delivery and stable operation.

And especially, experience in design and model testing.

At Newport News, turbine runners are continually being designed and redesigned for improvements in performance. And often upon receiving a contract for turbines, a model setting is built and complete tests made. So far, Newport News has filled turbine contracts with an aggregate rated output in excess of 7,000,000 horsepower.

Penstocks, spiral casings, valves, pumps, rack rakes and other essentials are also designed and built by Newport News. Our illustrated booklet, "WATER POWER EQUIPMENT," will be sent to you upon request.

Engineers . . . Desirable positions available at Newport News for Designers and Engineers in many categories. Address inquiries to Employment Manager.

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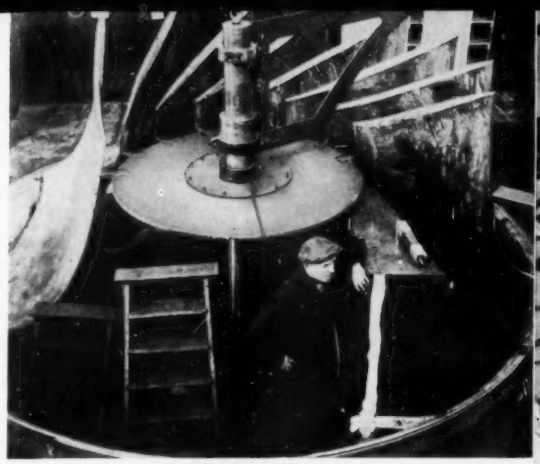
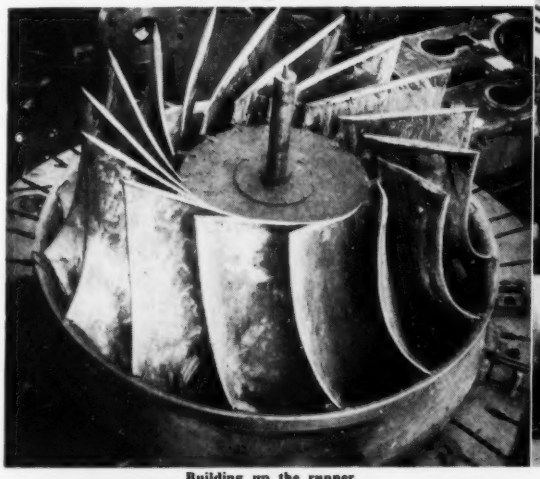
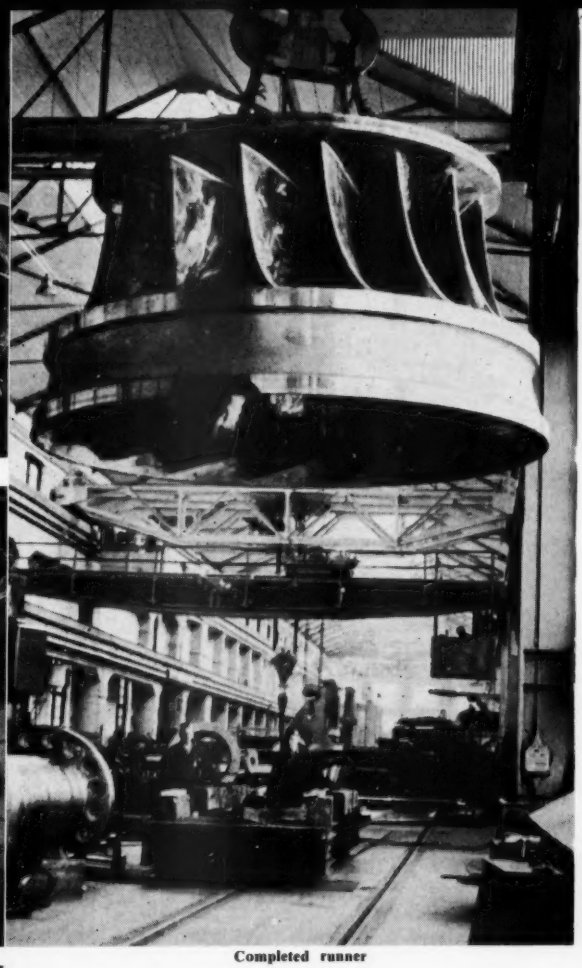


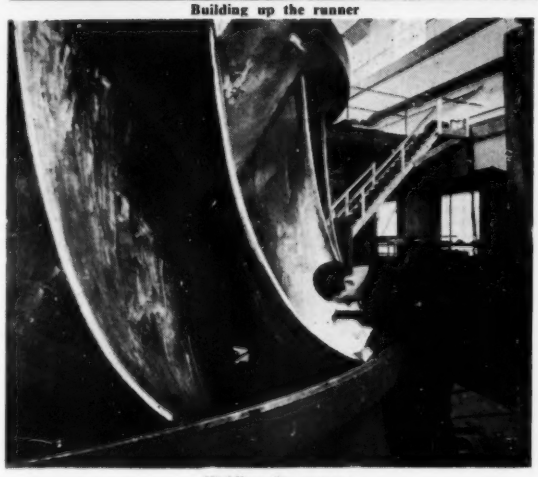
Building up the runner



Building up the runner



Completed runner



Welding the runner

Stress relieving furnace

The third KMW Turbine for the Swedish power plant Harrsele has now been put into service

With the installation of the third KMW turbine in the Harrsele Power Station, this plant has now been completed.

The first unit was put into service on August 15th, 1957, the second on January 29th, 1958, and the third on April 22nd, 1958. The total output amounts to 264,000 HP at a net head of 52.6 m (173 feet) and 125 r.p.m.

The runners are of welded construction according to our patented method. This construction ensures a better quality product and an improved hydraulic efficiency.

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In Switzerland

Operating at 9,000 ft. above sea level are five Bucyrus-Erie 54-B 2½ cu. yd. Ward-Leonard electric shovels loading blasted moraine rock for the huge concrete dam at Grande Dixence, Switzerland. Bucyrus-Erie excavators were preferred for their reliability in these tough conditions.

In Turkey

Development begins with excavation and for the dam construction at Damirköprü five 54-B machines are used. The Hydraulic Works Administration of Turkey are another organisation which prefers Bucyrus-Erie equipment.

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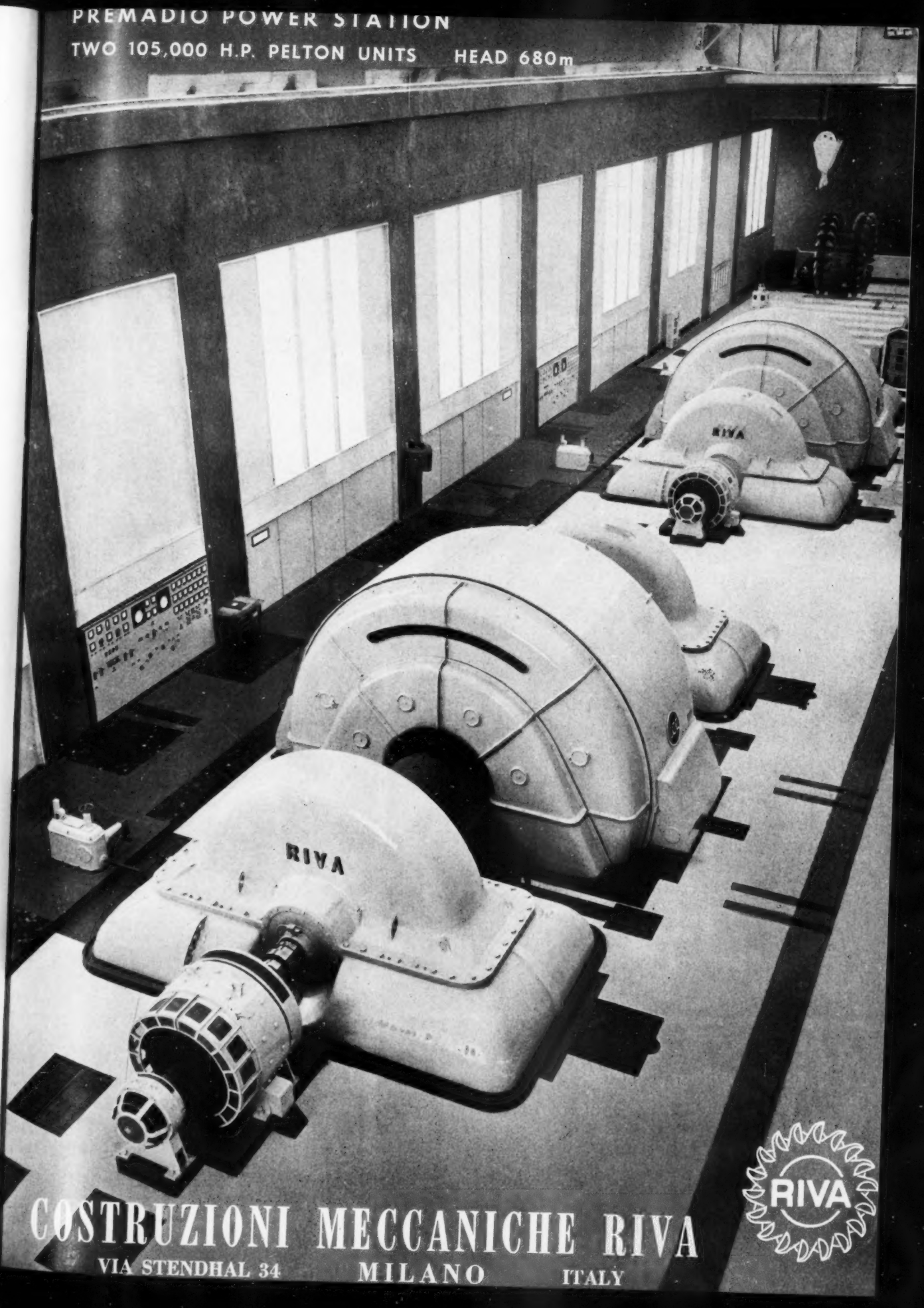
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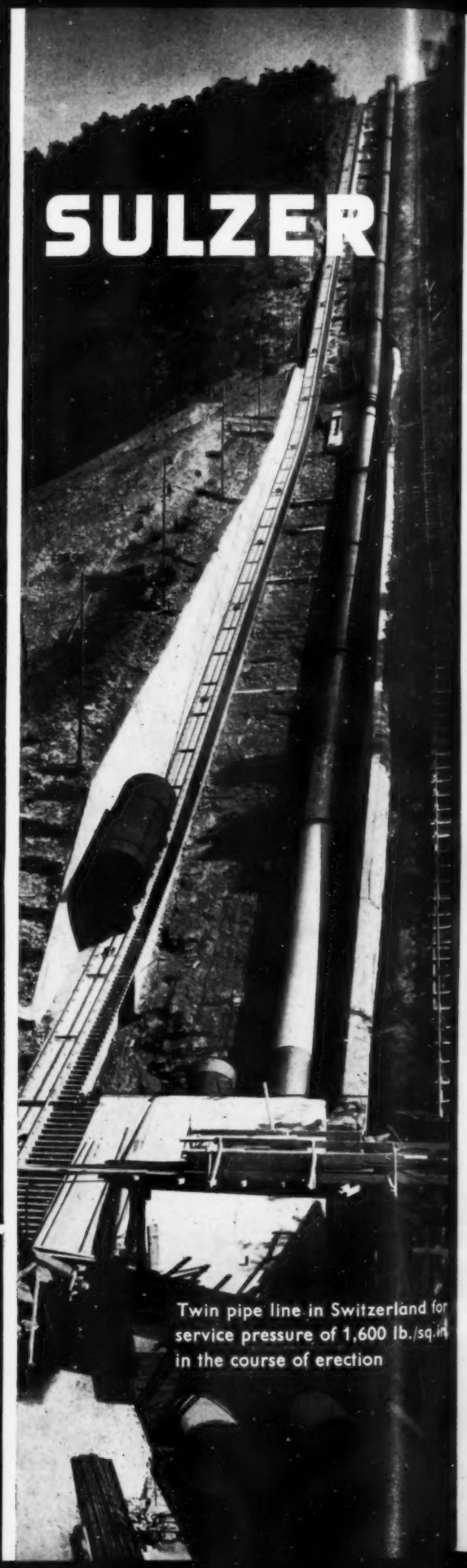

Twin pipe line in Switzerland for service pressure of 1,600 lb./sq.in. in the course of erection

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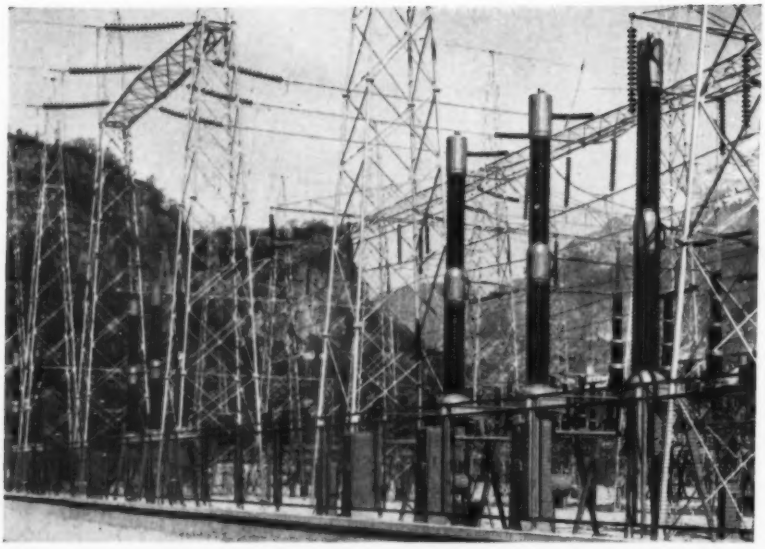

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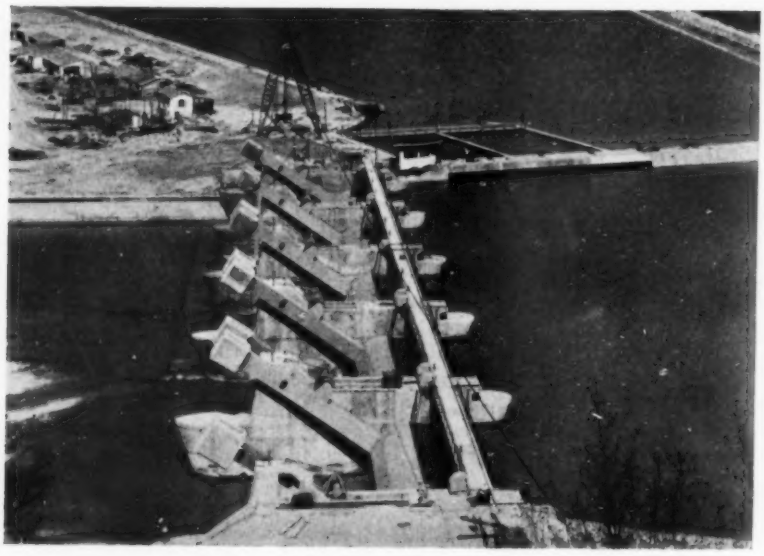

barrage on the Volturno river five automatic sector gates 25 mt. wide; 375 mt. high

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South America's largest Kaplan turbines to be delivered by NOHAB

Shown here are one of the discharge rings and a head cover for the Rincón de Baygorria Power Station, at the NOHAB works at Trollhättan, Sweden.

The three Kaplan turbines for the Rincon de Baygorria Power Station, situated on the Rio Negro, Uruguay, are now under construction in our shops.

Data:	
Head	14.7 m.
Rated output per turbine	49,500 h.p.
Speed	79 r.p.m.
Diameter of the runner	6.7 m.

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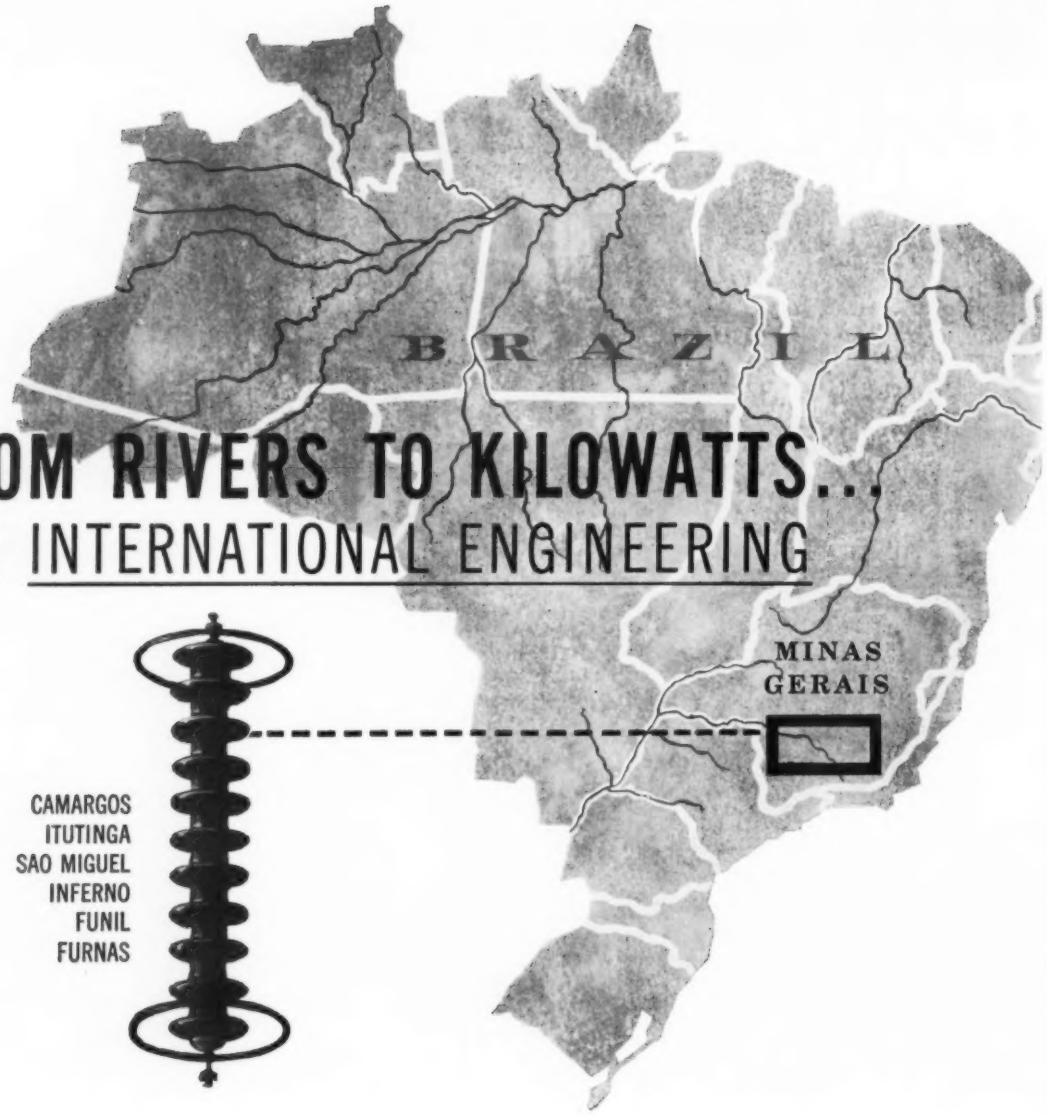

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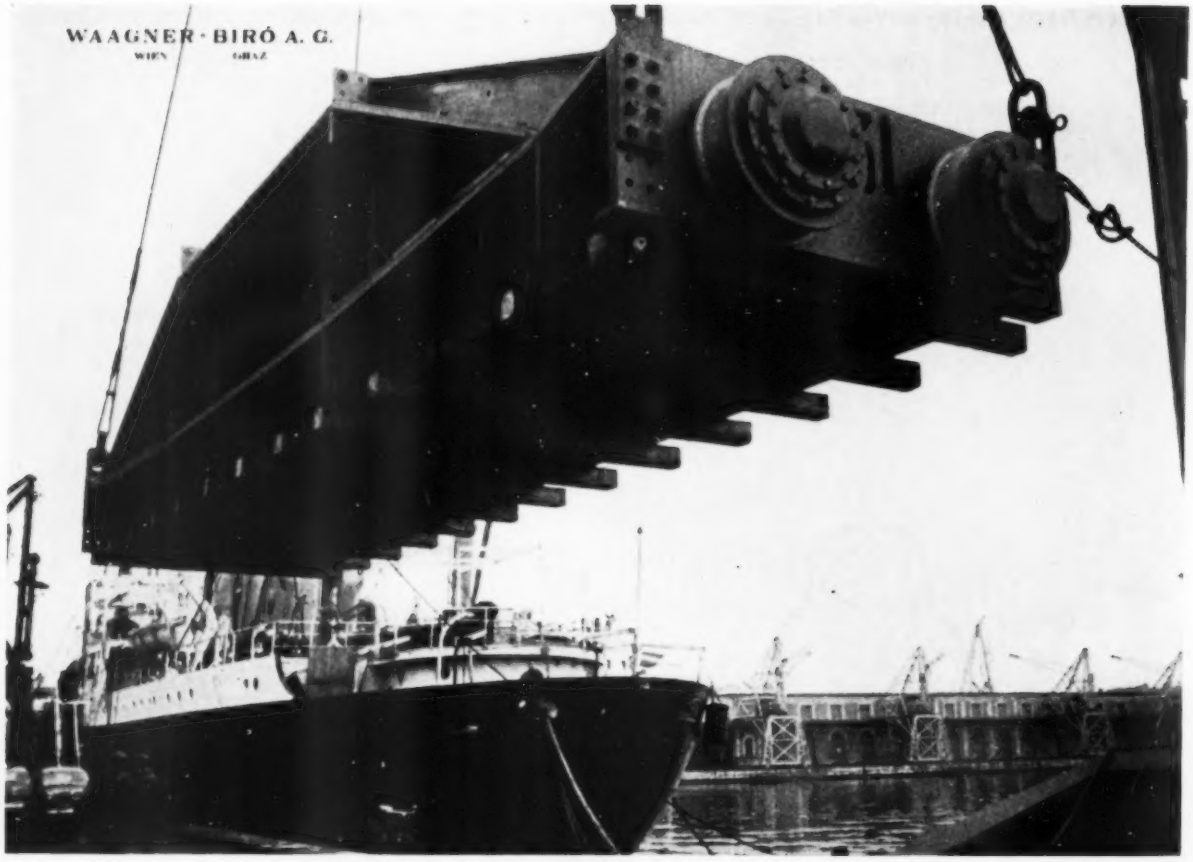

Transloading in the Port of Trieste of a part of an intake bulkhead gate for the Nile Power Station at Assuan. Five of these parts make up one complete bulkhead gate. Dimension of the gate 8 x 14 m.

●

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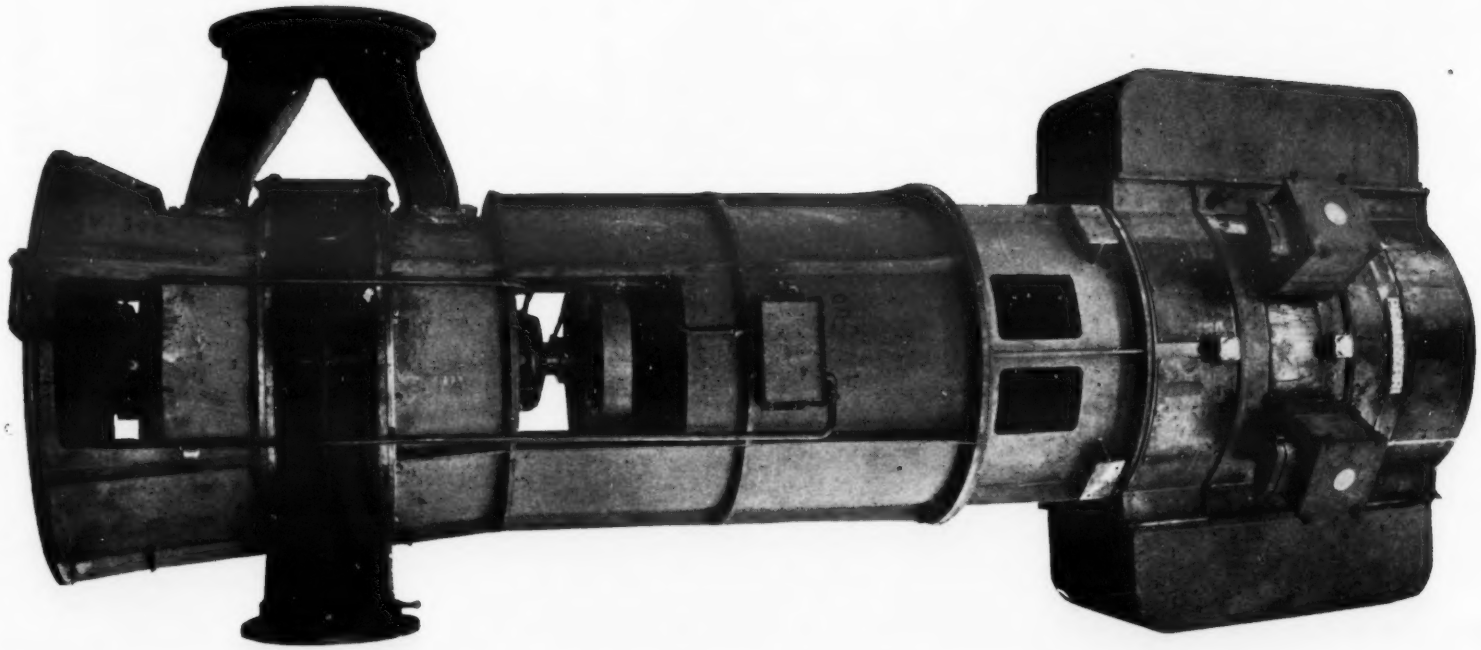
Driven by Electric Motor Type GASPV 1500/6 Rated Output h.p. 1700
Three phase Voltage Volt 3000 Frequency Hz 50
Rated Speed r.p.m. 980



Lilliputian and Brobdingnagian

Gulliver would have been quite at home on our Stand at the Electrical Engineers Exhibition surrounded by pygmies and giants of the insulator world.

The photograph re-produced above illustrates the vast range of porcelain insulators manufactured by Taylor Tunnicliff & Co. Ltd.; the smallest shown measures $\frac{1}{8}$" x $\frac{1}{8}$" dia. and the largest 12 ft. x 2 ft. dia. From the smallest to the largest they are all backed by the skill and knowledge of ninety years manufacturing experience.

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Pipe aqueducts totalling 5 miles in length and up to 60" in diameter have been laid by The Mitchell Construction Company on the St. Fillans section of the North of Scotland Hydro-Electric Board's Breadalbane Scheme. The aqueducts form part of the main civil engineering contract entrusted to the Company. The contract also includes nineteen miles of tunnelling in addition to generating stations and numerous intake works.

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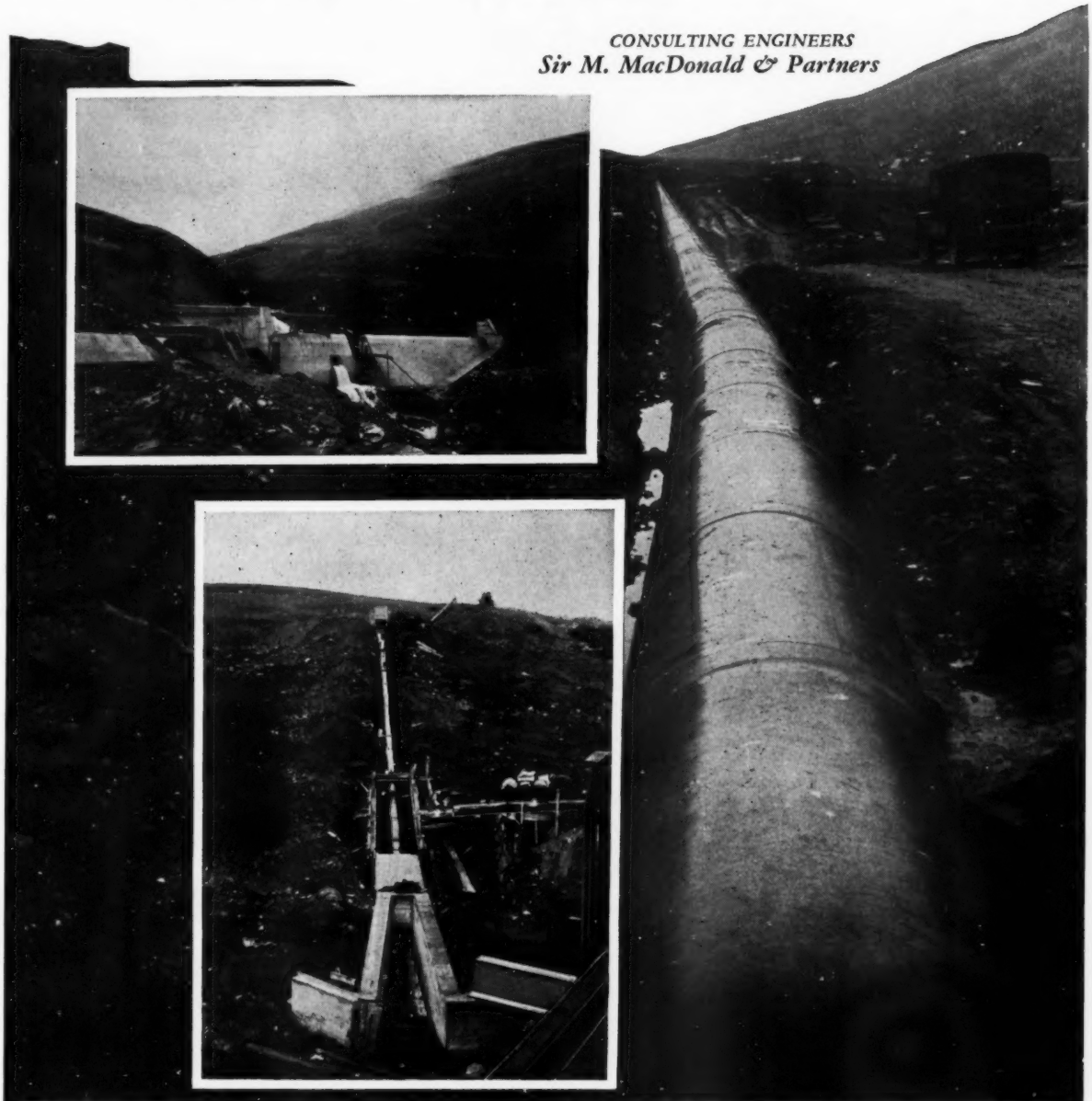

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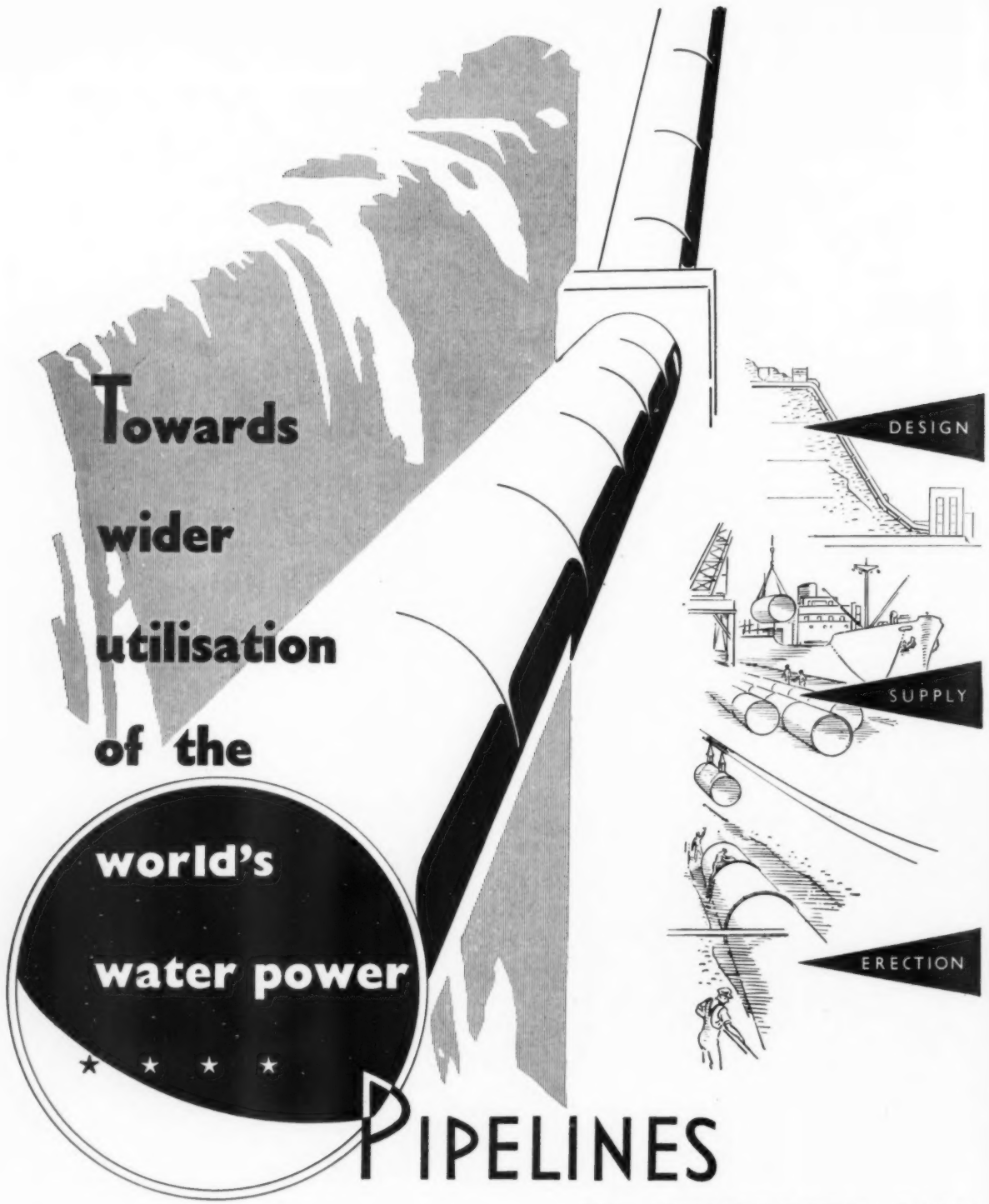
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of the
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water power
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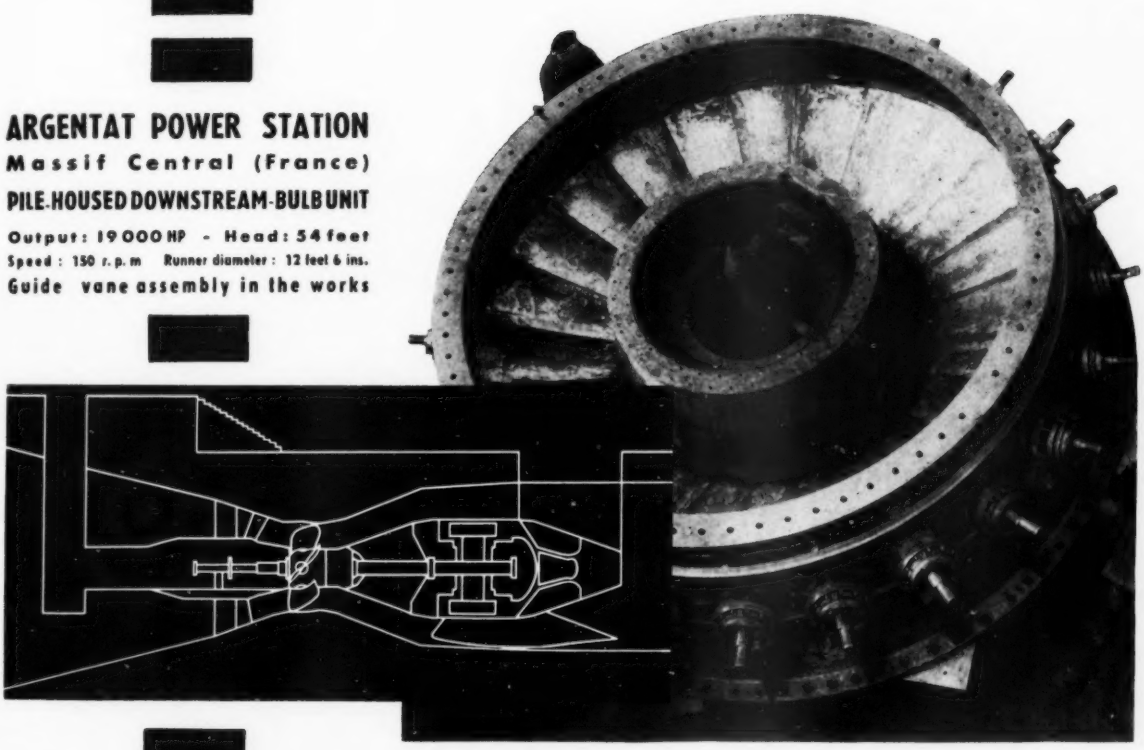

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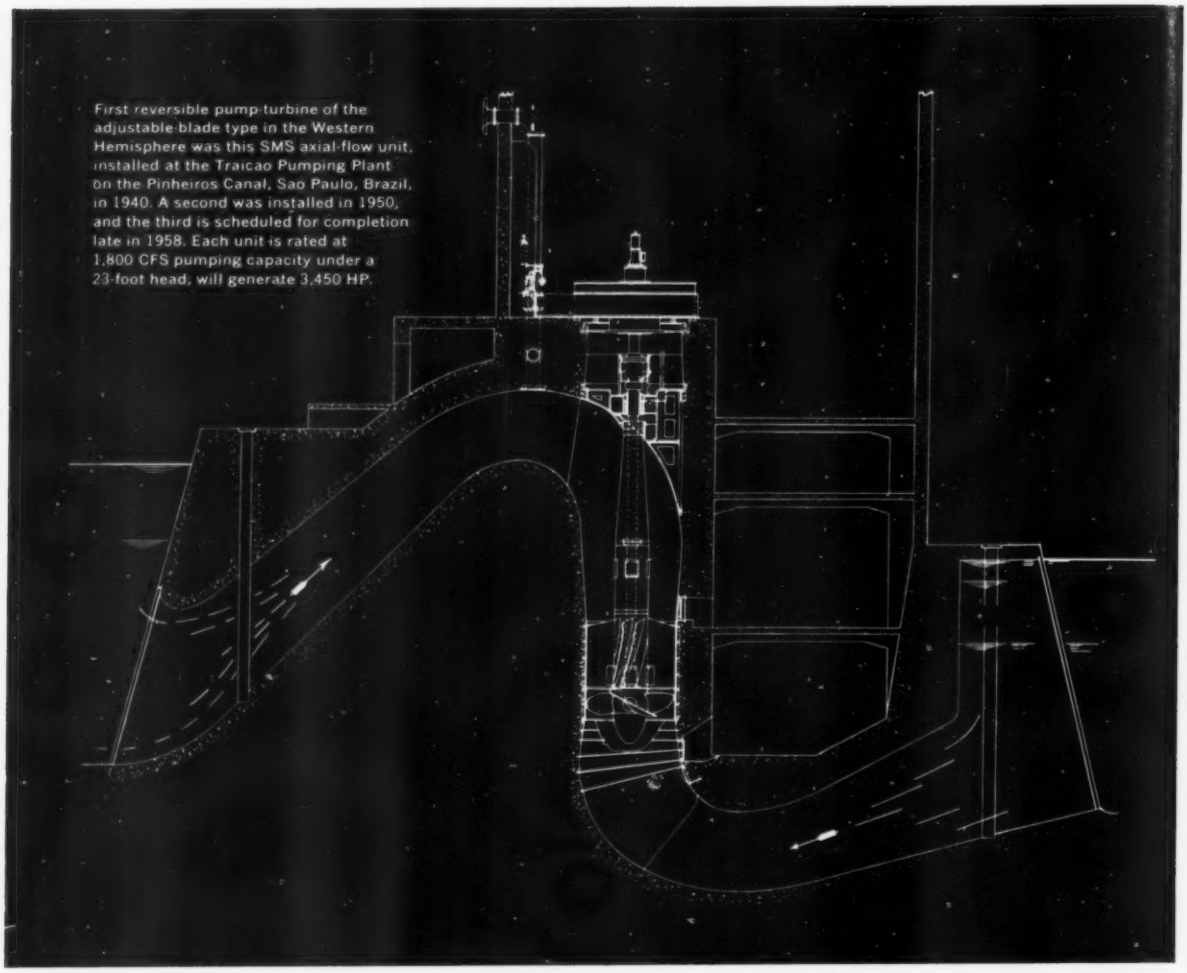

First reversible pump-turbine of the adjustable-blade type in the Western Hemisphere was this SMS axial-flow unit, installed at the Traicao Pumping Plant on the Pinheiros Canal, Sao Paulo, Brazil, in 1940. A second was installed in 1950, and the third is scheduled for completion late in 1958. Each unit is rated at 1,800 CFS pumping capacity under a 23-foot head, will generate 3,450 HP.

THIRD SMS PUMP-TURBINE UNIT ORDERED FOR TRAICAO PUMPING PLANT

These SMS adjustable-blade, axial-flow, pump-turbines at Traicao are the first reversible pump-turbines designed and manufactured in this hemisphere, and probably the only axial-flow units of this type in the world. SMS also manufactures other types. At the Pedreira Plant in Brazil, for instance, a more conventional centrifugal pump-turbine was installed in 1947. This SMS unit, operating under a 91.8-foot head, pumps 1,497 CFS at 138.5 RPM, and is rated at 16,000 HP when generating.

Recently, the Power Authority of the State of New York has placed an order with S. Morgan Smith for the manufacture of six pump-turbines for the Tuscarora Plant at Niagara Falls, New York. Each of these units is rated at 28,000 HP when generating, and at 3,400 CFS when pumping.

In addition to single-reversible, dual-purpose units like those at Traicao, Pedreira, and Tuscarora, SMS helped pioneer pumped-storage. The first large-scale application of separate pumps and turbines in the U. S. was for Connecticut Light & Power Company's Rocky River Plant, built in 1926. Here an SMS-Francis turbine, rated at 36,100 HP under a 226-foot head, was installed.

These installations are part of a broad background of experience in the engineering, designing and manufacturing of pump-turbines that is available to you at SMS. For information, write to S. Morgan Smith Company, York, Pennsylvania.

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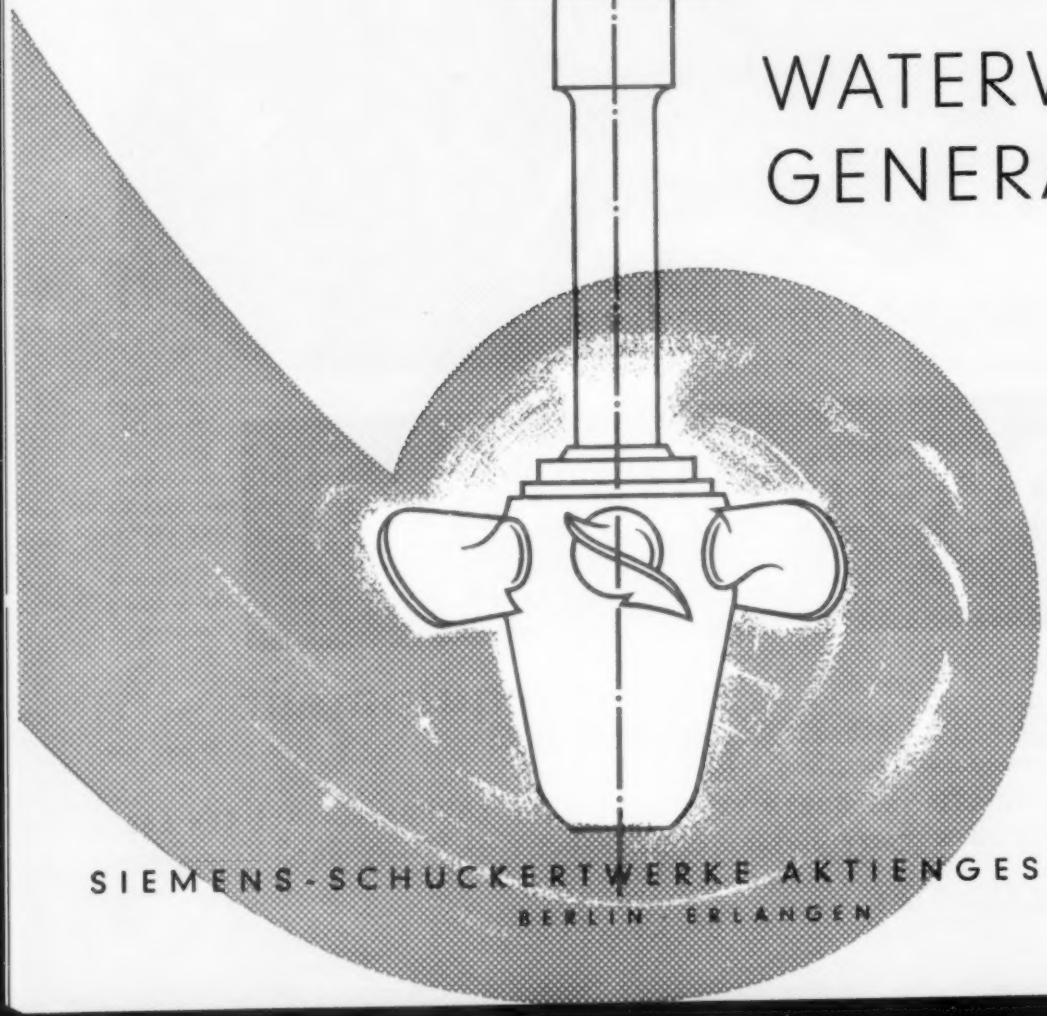

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WATER POWER

A technical journal devoted to the study of all aspects of Hydro-electric developments

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Volume 10 Number 10

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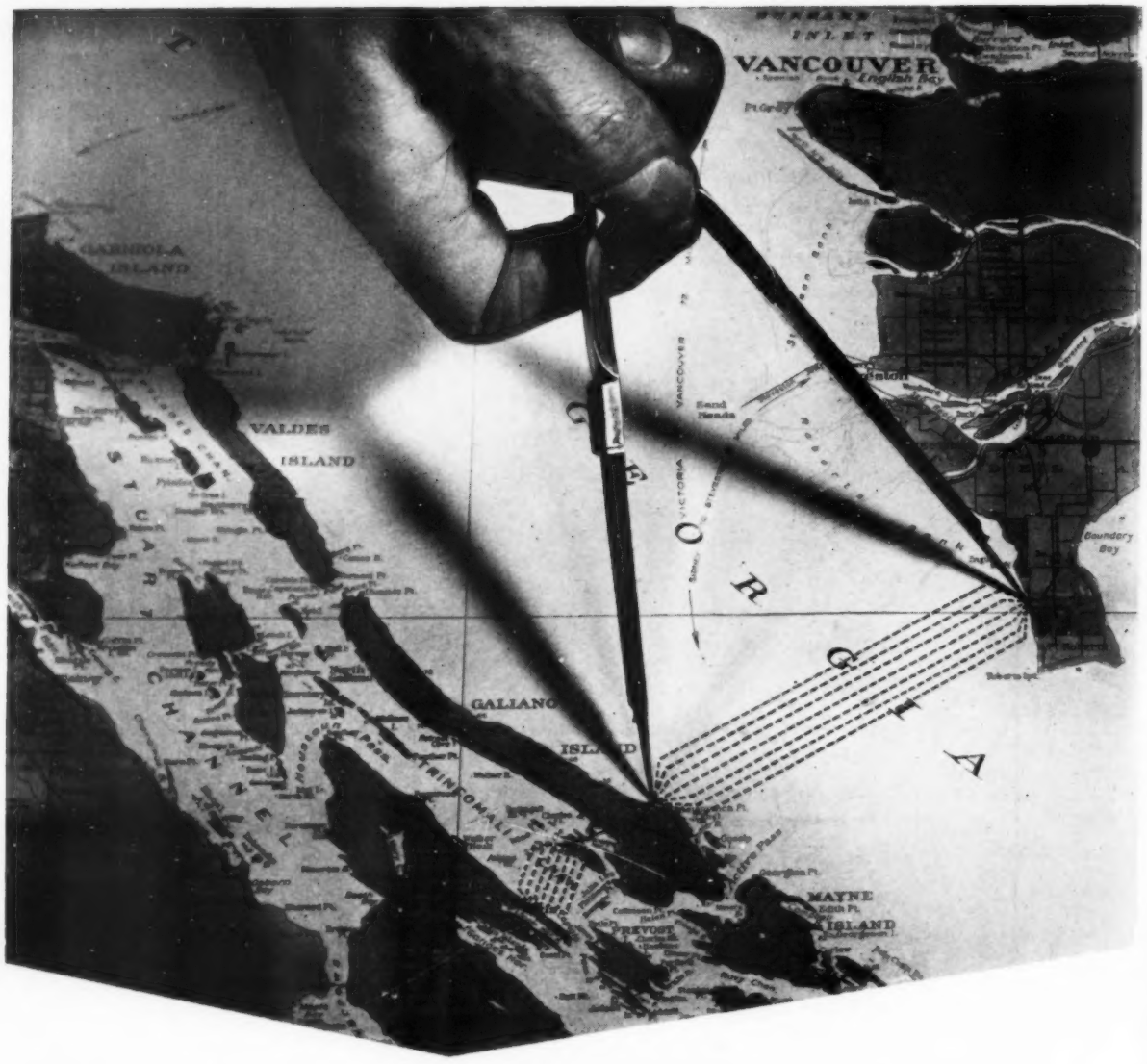

Yet another great power cable achievement!

A second circuit completed in the submarine power link between the British Columbia mainland and Vancouver Island

In September 1956 the first submarine power circuit between the British Columbia mainland and Vancouver Island was put into commission. It had been designed, made and laid by the BICC Group to transmit some 170,000 H.P. of hydro-electric power across the Georgia Strait and Trincomali Channel.

The link proved so outstandingly successful that a year after its commission, almost to the day, the British Columbia Electric Company awarded BICC another contract to supply a second circuit. This is now in service — after less than twelve months!

Altogether more than 133 miles of 138kV single core cable, including seven 16-mile continuous lengths,* have been made and laid by the BICC Group for this great power link, which now transmits 335,000 H.P.

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Integrated River-Basin Development

IN May 1956 the Department of Economic and Social Affairs, United Nations, instructed a panel of experts to prepare a report on the integrated development of river basins and their report has now been published.* The report is divided into five sections, the first of which defines in broad terms the concept of river-basin development and describes the evolution of techniques which have made integration possible, and the challenge which confronts the world in view of increasing populations and the consequent need to produce more food and power. The next section is concerned with the major steps to be taken once an integrated scheme has been planned and decided upon. Problems of an economic, administrative and social nature are then reviewed in detail and the report proceeds to examine the special difficulties which are likely to arise when a river basin extends over more than one country. Finally lines of action at national and international levels are suggested, within the broad framework of United Nations policy.

For a long time, the report states, engineers have tended to restrict projects to achieve a single purpose, that is, water supply, waterway communication, power production or land irrigation. This concept has not altogether disappeared, but newer engineering techniques developed since the beginning of the century have tended to favour the construction of combined schemes planned to serve several ends. In this context the development of the river Rhône is cited, where the total cost of navigation improvement and flood-control works has been offset by the revenue obtained from incidental hydro-electric generation. The magnitude of works of this kind and the large amount of capital involved brought them to the attention not only of engineers and financiers but also of statesmen, geographers, economists, agriculturists, and fishery, wildlife preservation and recreation experts. Excluding Antarctica and the extremely arid regions, the total land area suited to possible river development is estimated to be 125 million sq. km., but excluding doubtful areas this total is reduced to between 100–110 million sq. km. No estimate is given of the total power potential that is likely to be obtained on this land area, and indeed the data are not as yet available on which to base such an estimate; moreover the report is not primarily concerned with technical matters but rather with the broad lines along which the United Nations and its specialised agencies might suitably move to promote the orderly development of the rivers of the world.

Suggested steps to secure this end, particularly at the international level, are grouped into five classes of activity: (1) Improving the basic services in hydrological information; (2) improving the tools for analysis and for concrete action in the utilisation of water resources; (3) simultaneous scientific and technical investigations; (4) financial and technical aid to countries developing their river basins; (5) laying the groundwork for the reconciliation of conflicting interests in river basins which are divided by international boundaries.

With a basic report prepared on these lines the next step would be an appraisal of the physical possibilities of the basin; that is, the hydro-electric potential would be estimated and, if necessary, the irrigational potential. In addition any likely water surpluses or deficiencies in any part of the basin would be carefully noted. A further report would then be provided designed to exploit the potentialities to the full, assuming the basin to be under unified control and having only casual regard to the present historical patterns to the use of the land and water resources. A final step would then be to prepare an integrated plan giving proper weight to the human factors involved and to the existing works already established within the basin. The objective here, of course, would be to make optimum use of the resources, even should this involve the diversion of water from one basin to another or lead to changes in traditional uses, if it could be shown that clear advantages could be obtained, having regard to the necessity to provide adequate com-

* United Nations Publication No. 58.II.B.3 Price 5s. or $ U.S. 0.7.

pensation for those whose interests would be adversely affected, to secure the greater good of the community as a whole.

It would seem that the wide services the United Nations offer are likely to be of special value in regard to the so-called "less-developed countries" where modern industrial techniques and trained personnel are not available. In such instances expert advice could be given in regard to such matters as the collection of data, the assembling of technologists, contractors, and the provision of capital. Also it is in these undeveloped countries where the optimum employment of water resources is so necessary, for more often than not it is in just such countries that so much can be achieved in the way of providing power and improving crops.

World Power Conference Annual Report

THE World Power Conference Report for 1957 states that the International Executive Committee has accepted an invitation from the Spanish National Committee for a Sectional Meeting to be held in Madrid in 1960. Following a further invitation from the Swiss National Committee, it has also been decided that the 1964 Sectional Meeting will be in Switzerland.

A sub-committee of the International Commission on Large Dams has been editing the second edition of the Technical Dictionary on Dams and it is expected that the printing of this work will be completed during August 1958. The dictionary contains indexes in French, Italian, Portuguese, Spanish, German and English.

Volta River Project

RENEWED efforts are being made to raise finance for the Volta River scheme in Ghana. Mr. Gbedemah, the finance minister of Ghana, visited the United States recently with a view to enlisting the aid of the American Government and it is now understood that a group of experts will visit Ghana shortly to make a new assessment of the economic possibilities. When first broached the project was primarily intended for the production of aluminium, using a nearby deposit of bauxite, but more recently an ambitious scheme of irrigation has been attached and some doubt has been felt as to the amount of firm power that will be available for aluminium production.

New Stations in Luxembourg

ALTHOUGH Luxembourg is served primarily by thermal stations, two new hydro-electric stations are under construction on the Sûre. A peak-load plant is being built at Esch sur Sûre which will operate for four hours a day and will produce 12 million kWh per annum. A reservoir having a live storage of 53 million cu. m. will supply two 6,400 kVA Francis sets at a mean head of 36·7 m. The alternators will generate at 6·3 kV, and three-coil transformers will step up to 15 kV for local supply and to 65 kV for the national grid, which will be supplied through an outdoor switchyard.

About 2½ km. downstream of the station a 360,000 cu. m. compensating basin is being constructed to prevent flooding of the country while the station is operating, and the head between the station tailrace and this basin will eventually be developed by turbines driving induction generators which will be connected to the 15 kV system.

The other station will be at Rosport near the town of Echternach on the German-Luxembourg frontier. It will be a run-of-river station generating 20 million kWh per annum. It will contain two Kaplan turbines operating under a normal head of 9·2 m. and a maximum head of 11·6 m., and driving 3,800 kVA alternators. The electrical system will be similar to that obtaining at Esch sur Sûre.

All the main electrical apparatus for both of these stations is being supplied by the Austrian firm of ELIN, and erection of the equipment at Esch sur Sûre has already commenced.

Cloud Seeding in Australia

AUSTRALIA'S Commonwealth Scientific and Industrial Research Organisation reports substantial success with its long range rainmaking experiments.

Seeding of clouds with silver iodide over the past three years has increased the normal rainfall over the Snowy Mountains area of southern N.S.W. by at least 15 per cent. However, to be sure of the results, the C.S.I.R.O. will continue the tests for up to 10 years. Similar tests are being conducted in South Australia and an area in northern N.S.W. has also been selected for experiments.

Pasvik River Development

THE joint Russo-Norwegian venture for hydro-electric development of the Pasvik River, mentioned in our issues for May and September 1957, is now in the design stage. An agreement has recently been concluded between the Soviet Ministry of Power, in conjunction with the Soviet organisation Technopromexport, and the Norwegian firm K/S A/S Novelektro. The latter company, which has been formed by Noveno (the Norwegian counterpart of Technopromexport) and the A/S Hafslund power works, will supply the plans for the 35,000 kW Boris Gleb power station which Russia intends to build as part of the Pasvik River project. Two further power stations, of 18,000 kW and 17,000 kW capacity respectively, will eventually be built at the southern end of the river and all the power produced by the three plants will be used by the U.S.S.R.

Hydro-Electricity in Ireland

THE Thirty-First Annual Report of the Electricity Supply Board of Ireland has now been published and gives the usual information on water power investigations and the hydrometric survey that is being made. Excluding the Lee and Clady, seventeen undeveloped rivers are under investigation, and the collection of hydrometric data on the Shannon, Liffey, Erne and Clady is being continued. Last year the inflows at the existing water-power plants on the Shannon, Liffey, Erne and Lee were about 90% of the long-term mean flows, being well below normal during the May to August period but favourable for power production for the rest of the year. Utilisation of the available flows amounted virtually to 100% except in the case of the River Lee stations, Inniscarra and Carrigadrohid. The two sets at Inniscarra, one of 15,000 kW

and the other of 4,000 kW, were put into operation in May and August respectively and the 8,000 kW unit at Carrigadrohid was commissioned at the beginning of November 1957.

On the River Clady, construction of Cung dam at Dunlewy Lough and the weir at Gweedore is nearly completed and work on the banks and the lining of the headrace canal is likewise nearing completion. Erection of the power-house superstructure is making good progress and the station is expected to be producing power before the present year is out.

Koombooloomba

A NEW 115 ft. high dam and power station are now in the course of construction in the relatively undeveloped region of North Queensland, Australia. Koombooloomba power station, which will have a capacity of 72 MW, is being built on the Tully River and the power will greatly accelerate agricultural expansion and modernisation over a wide area. It is expected that the project will be completed in about four years. Two 54-RB 20 ton track-mounted cranes are being used on the site. The reservoir will have a surface area of 146,000 acre-ft.

Mihoro Dam, Japan

CONSTRUCTION work on this dam was begun in April 1957 and it is expected that the scheme, including the 215 MW power station, will be completed by April 1961. It is a rockfill dam and operations were recently enlivened by a 156 ton dynamite charge in a nearby quarry face to provide fill material. The local inhabitants made the occasion an excuse to have a gala day and the children especially seem to have had the best of good times. This is the first rockfill dam to be built in Japan and is designed to have a height of 425 ft. and a crest length of 1,400 ft. The project was initiated by the Power Resources Development Company and the main constructional contractors are the Hazama Gumi concern, assistance being given by the Guy F. Atkinson Company of the United States.

Uganda Power Extensions

THE Uganda Electricity Board have announced plans to supply power to an area between the Lake Albert escarpment north of Fort Portal and Kasese in the foothills of the snow-capped Mountains of the Moon, some 200 miles from Kampala. This supply will be provided in the first place by taking a bulk supply from Kilembe Mines, near Kasese; later, as and when required, additional power will be derived from a local run-of-river 3,000 kW hydro-electric plant using the waters of the Muzizi River, which flows over an escarpment 1,400 ft. high into Lake Albert near Ndaiga at the southern end of Lake Albert. The capital cost of the project will be rather more than £400,000. The capacity of this project can, if required, be increased to 7,500 kW.

Discussions are at present going on with Kilembe Mines regarding the provision of a bulk supply from their Mobuku River hydro-electric project. If these are successfully concluded, the transmission and distribution lines will be erected first and a supply will possibly be available in the area towards the end of 1960. By this means, too, it will be possible to defer the construction of the Muzizi scheme and thus postpone the need for scarce capital.

In the Muzizi project, water will be abstracted from the river a short distance above the start of the Muzizi gorge. From the intake it will be conveyed by an aqueduct about 6,200 ft. long to an open forebay near the top of the escarpment, and thence by a steel pipeline about 4,400 ft. long to the power station. The initial installation will consist of two 750 kW Pelton sets, with a third set of approximately 1,500 kW capacity to be added later.

Studen Kladenets Dam

BULGARIA now has an installed capacity of 326,450 kW from hydro-electric power stations and the combined output from thermal and hydro-electric plant is expected to be about 3,000 million kWh for the current year.

The Studen Kladenets dam on the Arda River, which was officially opened on June 15, 1958, is 223 ft. high, 630 ft. long and has a storage capacity of 489 million cu. m. The four 15,000 kW capacity generators will supply the country with some 210 million kWh of electricity each year. Construction work began in July 1954 but some delay was caused by severe flooding at the end of that year and in early 1956. A special concrete-mixing plant enabled over 350,000 cu. m. of concrete to be laid in a period of 27 months.

The Studen Kladenets dam and power station is the major unit in the Arda River power project which, when completed, will greatly enhance industrial expansion in this remote and undeveloped region.

The Second Five-Year Plan in India

INDIA has now completed her first five-year plan for economic and industrial development. In 1951, power available from all sources was only 2·3 million kW, and because energy is essential for any form of industrial expansion, the first plan included a comprehensive range of projects for thermal and hydro-electric power generation. The second five-year plan is now beginning; it includes no less than 182 new power schemes which, when completed, will increase the present installed capacity of 3·4 million kW to 6·9 million kW. There are about 4,000 towns in India with a population of between 5,000 and 20,000 and during the next five years a large proportion of these centres will be connected to the national grid.

In this extensive programme for development there has been a growing need for a regular supply of trained engineers and technicians, and a committee, appointed to study the present and future manpower requirements for long-term river valley development, has recently published a report which states that present training facilities are inadequate, and that much will have to be done before the supply of fully qualified personnel equals the demand.

Certain innovations have been made as a result of experience gained during the first plan. India is comparatively short of foreign exchange and economy is therefore of paramount importance; the National Projects Construction Corporation has been formed by the Government to carry out the civil-engineering and construction work for state-financed projects within the plan, thus eliminating private contracting companies and streamlining procedure from the

design stage onwards. A further advantage is that there will be a permanent pool of men experienced in all forms of civil-engineering work and it will be easier to make the maximum use of a highly-trained mobile labour force under one central management. The Central Water and Power Commission has established an organisation to control and co-ordinate purchases and use of construction equipment, to enable machinery to be employed successively on several different projects.

The rate of industrial and economic progress in India during recent years could never have been attained without carefully planned development of the country's hydro-electric resources. There have been many difficulties and a certain lack of preliminary study has delayed the work on some sites, but the first plan has served to establish a sound practical policy for the second and subsequent phases of expansion.

More Power for Ecuador

A NEW hydro-electric project on the San Pedro river in Ecuador has now reached the planning stage. Some 845,000 cu. m. of material will be excavated to form the storage reservoir and the power station will ultimately supply the capital, Quito, with a further 40,000 kW. This project is the most important undertaken in Ecuador in recent years.

Storr Lochs and Moriston Extensions

EXTENSIONS costing an estimated £740,000 to be made at the existing hydro-electric schemes at Storr Lochs in Skye and on the River Moriston in Inverness-shire have been approved by the Secretary of State for Scotland. At Glenmoriston, the North of Scotland Hydro-Electric Board proposes construction of an aqueduct to extend the catchment areas regulated by Loch Cluanie, main reservoir of the scheme. Implementation of this scheme will increase the output of the two upper generating stations, Ceannacroch and Doe, by some 12·2 million kWh annually. Cost here will be £690,000. At Storr Lochs, the headwaters of the river Chracaign will be diverted into Loch Fada, thus enabling the Board to release part of the yield of water of high quality from the Storr Springs for supply to Portree and the surrounding area. This latter project is being undertaken at the request of the County Council of Inverness. The Board will also increase the output from the Storr Lochs project by some 1·5 million kWh annually. Estimated cost is £50,000.

N.Z. Weather Data System

NEW methods are now being used to keep New Zealand's weather statistics. At the meteorological office, Wellington, and to a lesser extent in Christchurch and other district offices, a punch-card system has been in use for several months.

At Harewood (Christchurch) the upper air observations from the radiosonde balloons have been recorded by this method, which has already proved so successful that it will be greatly extended in the future.

Where this system has been introduced the figures no longer have to be written on data sheets by hand, added, averaged, rewritten and filed. Upper-air observations are now quickly marked, in pencil, on the cards, which are then sent to Wellington for punching, processing and tabulating on a master machine. This punch-card system was first applied to meteorological work by the United States Weather Bureau, and has quickly become popular, and the American bureau now has 200 million cards in its files.

Rain

THE average rainfall for August in England and Wales is no less than 3·6 inches, a figure which is exceeded only by October (3·9 in.) and December (4·28 in.). Although the fundamental requirement for all hydro-electric development is water in one form or another, the hydraulic engineer is presumably as subject as anyone to a feeling of impotent fury when the local climate is considered.

There is no foundation in fact for the common belief that the weather was better some 20 or 30 years ago, or the oft-repeated fallacy that nuclear tests upset the delicate balance between sunshine and precipitation. Meteorological office records show that there has been little or no change in the amount of rainfall in the United Kingdom for more than a hundred years past and it therefore seems unlikely that there will, at least in the foreseeable future, ever be anything but a temporary and local need for chemically induced rainfall in this country.

Correspondence

Electricity Supply in Portugal

To the Editor, WATER POWER

In your September 1958 issue you remark on the decrease in electricity supply in Portugal in 1957. I wish to correct certain of your statements, which are misleading.

The actual production is as you state, but this was due to the very low flows because of the dry year. However, apart from the electro-chemical industries which can only work, by an official agreement, on hydro-electric production, and therefore during dry years they are only working part time, consumption increased. We therefore have the following figures:—

	1956	1957
Permanent consumers ...	1,502 GWh	1,680 GWh
Electro-chemical industries	454 „	290 „
Thermal production ...	140 „	328 „
Hydraulic production ...	2,036 „	1,841 „
Total production	2,176 „	2,169 „

From the above you can see that if the electro-chemical industries had worked at the 1956 level, the total production would have been 2,333 GWh.

However, as the installed power of these industries was increased in 1956, the consumption would have been higher. This year they are working at full capacity and their consumption from January to July 1958 was 300·2 GWh, and for 1958 it is estimated they will require 580 GWh or double 1957. Permanent consumers are again up about 10%.

ENGO. JOSE MORBEY AFFONSO,
Chief Electrical Engineer, Hidro Eléctrica do Zêzere.

Patterns in Hydrology

By N. J. COCHRANE, B.Sc., M.I.C.E.*

THE hydro-electric engineer is greatly dependent for his success on the behaviour of the natural phenomena he seeks to control, but to a great extent his comparative ignorance of climatic and meteorological mechanisms enforces a passive acceptance of these elements. Their vagaries often reduce him to inferring somewhat problematical statistical probabilities, and sometimes he is compelled to descend into a complete limbo of randomness.

For some years the author has been interested in climatic patterns and considers that several climatic phenomena exhibit marked cyclical behaviour with a fairly good qualitative correlation to the rate of change of sunspots, though not with the sunspots themselves. At the time of writing, July 1958, two quantitative predictions of the behaviour of the Lake Nyasa-River Shire complex in Nyasaland, have been made and the results are given in Table I.

TABLE I.

Year	Wet Season Free Water (in. on the lake)		Residual Annual Free Water (in. on the lake)	
	Predicted	Actual	Predicted	Actual
1957	56½	60	27½	28
1958	39½	36	6	abt. 4

From the record the complex has shown wet-season free waters of from 15 in. to 78 in. on the lake and residual annual free waters from −30 in. to +46 in. so that there is a considerable range of values to choose from. (A difference of 12 in. on Lake Nyasa represents about 10,000 cusecs for one year.)

If attention is turned to the British climate, other results may be adduced, and so far as, say, the River Moriston in Scotland is concerned, attention is drawn to Fig. 1. Much hydro-electric development has been, and is, taking place in the mountainous areas of Scotland, and it might be reasonably deduced by an operator of a hydro-electric station on the Moriston that he could expect his output of power to be reduced as the rate of change of sunspots increased, or *vice versa*. Planning in advance is consequently a possibility.

The diagram is plotted on the basis of three-year means and the interpretation should be mainly on this basis also. Insofar as the behaviour of certain aspects of sunspots can be predicted it is also possible to deduce some kind of answer on an annual basis.

It should be noted that the Moriston behaves in the opposite sense to a river like the Severn or Thames in southern Britain.

On Fig. 1 the flood flows in the Severn and Thames are also plotted and it will be observed that the results would have some significance to, say, a contractor building a dam or some other work on either river. If, for example, his construction takes place in a period of low rate of change of sunspots, then he could have some expectation of lessened trouble from flooding, and *vice versa*. These inferences raise certain questions about the applicability of the usual probability analysis to the incidence of floods, and the author draws the tentative conclusion that if the probability method is used it should be interpreted in the sense that the probability varies with the particular time which is of interest and is not a fixed figure.

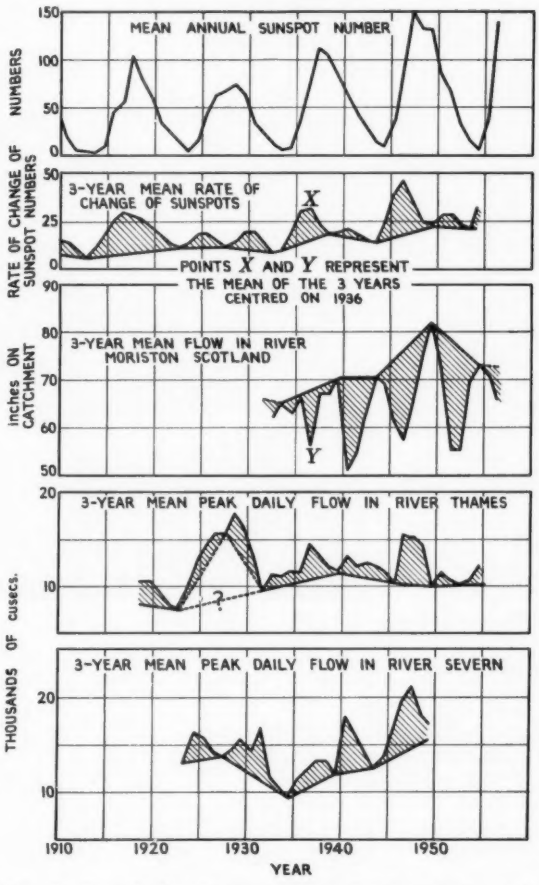

Fig. 1. Correlation between river flows and sunspot cycles

The method demonstrated here by the author is too coarse to justify entirely the accuracy of the first two predictions given in Table I, but at least the results are better than the nothing he had before, and may be of some interest to practising engineers, although many data remain intractable.

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Fig. 12. Santa Massenza machine hall

The Sarca-Molveno Scheme

This final article is devoted to a description of Santa Massenza station, which is the largest in Italy and was designed to meet special hydraulic and electrical requirements

PART TWO

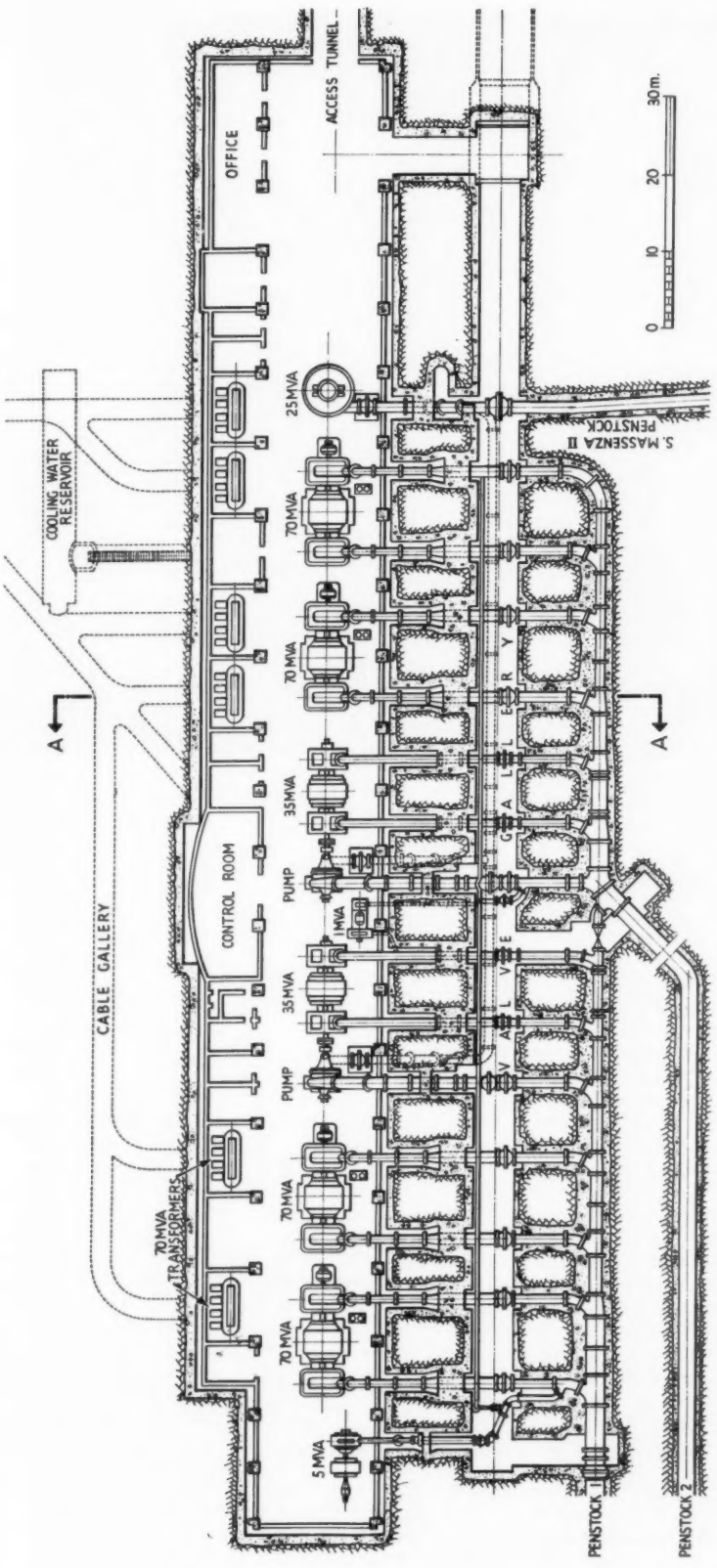
IN our previous article we described the civil-engineering and hydraulic features of the Sarca-Molveno scheme, which, when fully developed, will have an installed capacity of 655 MVA. The proprietors of this development, it will be remembered, are S.I.S.M. (Società Idroelettrica Sarca-Molveno), a company formed jointly by Società Edison, Milan, and Società Idroelettrica Piemonte, Turin.

Santa Massenza station holds a key position in the scheme, as it is the largest of ten stations that will ultimately be built, and, in fact, is the most powerful station in Italy. Its installed capacity is 388 MVA and its average annual production 637 million kWh.

A general view of the machine hall appears in Fig. 12, and a plan and cross-sectional elevation in Fig. 13, but the design of the power station can be fully appreciated only by taking into account the hydraulic and electrical conditions with which it has to comply.

On the hydraulic side, nearly the whole of the plant is supplied from the seasonal storage in Lake Molveno under a gross head ranging from 460 to 590 m. and is designated "Santa Massenza I," but a relatively small proportion of the capacity is fed from Ponte Pià reservoir at a gross head of 202·7 m. and is known as "Santa Massenza II." Ponte Pià reservoir has a live storage of only 1½ million cu. m., and to save spillage during the spring floods, pumps are to be installed to transfer surplus water from Ponte Pià to Lake Molveno.

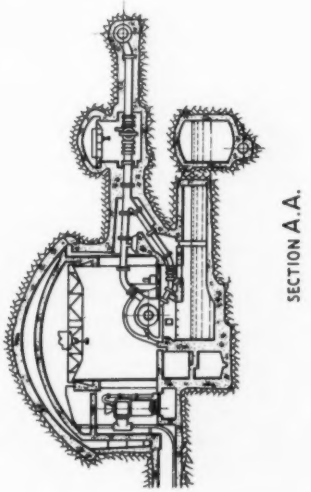
Electrically, the station has vital functions to per-



form. Its primary requirement is to feed the 220 kV system of the two power companies—Edison and S.I.P.—responsible for the development, and it must supply them independently, so that, in fact, the plant functions virtually as two separate generating stations in one hall. Secondly, it plays its part in supplying the 220 kV trunk line connecting central and southern Italy to the power plants of the north. For all these services it has to be capable of acting either as a base-load station or as a frequency-control station.

The size, type and disposition of the various units have been selected with the foregoing requirements in view, coupled, of course, with the usual considerations of engineering economics. In the first place, two 35 MVA generating sets were built, arranged for connection to the pumps that will ultimately be installed for water storage, and the size of these sets was chosen primarily to suit the capacity and characteristics of the pumps. The need to supply two independent 220 kV systems in addition to the north-south trunk transmission line, using machines large enough to be capable of frequency control, was met by the installation of four

Fig. 13. Plan and transverse sectional elevation of Santa Massenza station



70 MVA generating sets. Santa Massenza II consists of one principal machine of 27 MVA, the size of which was related to the available water reserves at Ponte Pià. For auxiliary services a 5 MVA set has been installed, supplied from Lake Molveno, and space is available to install a second 5 MVA set if required, to be supplied from Ponte Pià. A 1 MVA set is also in service for low-voltage station supplies. This set is fed from Lake Molveno, but it is so arranged that a second turbine, fed from Ponte Pià, can be installed as an alternative drive.

For the high-head machines, Pelton wheels were the natural choice, and the horizontal arrangement was preferred because of the ease of erection and maintenance and the absence of a thrust bearing. Considerations of specific speed led to the presentation of two alternatives—a two-runner single-jet machine running at 300 r.p.m. or a two-runner double-jet machine running at 428·5 r.p.m. The latter was selected on account of the reduction it offered in the size and cost of the alternator. This choice, of course, involved the bifurcation of the pipes supplying the nozzles, and to provide these pipes with bends of ample radius the spherical valves had to be arranged at some distance from their respective turbines. This was achieved most economically by excavating a separate valve gallery, as seen in Figs. 13 and 14, affording a distance of 22 m. from the valve outlet to the turbine shaft.

The Santa Massenza II 27 MVA set was within the head range where a vertical Francis machine was the obvious solution.

Reasons of ordinary economics led to each of the larger generators being solidly connected to a single 70 MVA three-phase transformer, each transformer being housed in a cubicle at the side of the machine hall immediately opposite the generating set it serves, so as to minimise the length of 15 kV busbar. For reasons of standardisation, both 35 MVA machines are connected through circuit breakers and isolators to a single 70 MVA three-phase transformer of identical construction to those serving the 70 MVA machines. Connection to the outdoor switchyard is made by high-voltage oil-filled cable, and a run of about 500 m. of 15 kV busbars, which would have been needed if the transformers had been placed out of doors, has been avoided.

The electrical system conditions imposed stringent requirements on the characteristics of the alternators and on their regulating gear. The alternators have a high short-circuit ratio and are capable of a large degree of negative excitation, and a power-frequency system of regulation has been provided which is one of the first of such installations in Italy.

The control room annexe is strategically placed halfway along the side of the machine hall. It is on three floors, the control room itself being on the centre floor and overlooking the machine hall.

The machine hall, a view of which appears in Fig. 12, is 193 m. long, 29 m. wide and 28 m. high. Parallel to it but separated by a rock pillar about 12 m. thick is a valve gallery (Fig. 14), 5 m. wide by 8 m. high, and almost vertically below the valve gallery is the discharge tunnel.

Spherical Valves

Although more than one manufacturer was concerned in supplying the turbines, it was decided that

Fig. 14. The valve gallery

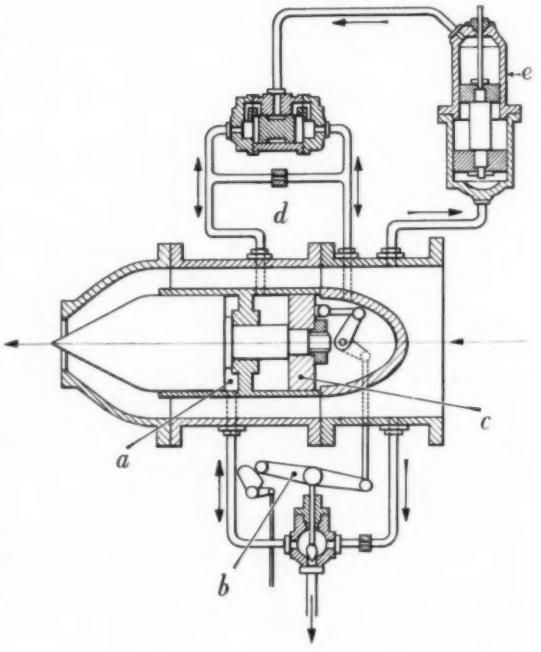


Fig. 15. Needle control on Franco Tosi turbines

for reasons of uniformity in design and in system of control the turbine valves should be provided by one firm. Franco Tosi S.p.A., Legnano, who built the four 70 MVA turbines, were therefore called upon to supply the valves for these machine and also for the two 35 MVA sets, there being, of course, two valves for each turbine, one for each runner. Immediately downstream of each valve a short removable section has been introduced into the pipe to enable a duplicate valve to be installed should it later be considered desirable. A venturi section is located immediately upstream of each valve.

These valves are of the spherical type, the larger ones having a bore of 1,000 mm. and the smaller ones 700 mm. The spherical member is rotated by a servomotor supplied with filtered water from the penstock, and the valve is sealed in the closed position by a movable stainless-steel sealing ring mounted immediately upstream of the spherical member. This ring has a collar formed on its periphery which works in an annular chamber; water pressure introduced on one side of the collar forces the ring against a seating on the mating face of the spherical member, whereas water pressure on the other side of the collar withdraws the ring. When the valve is opened the ring is first withdrawn and the spherical member then rotated; to close the valve the motions take place in the opposite sense and sequence. The movements of the ring and of the valve are interlocked to render a faulty sequence impossible, and the entire operation is remote controlled from the turbine control panel or from the control room.

Fig. 16. Turbine regulator unit

The 70 MVA Turbine

The four 70 MVA generating sets are two-bearing machines having a Pelton runner overhung at each end of the generator shaft, each runner being driven by two jets. As already mentioned, the turbines were built by Franco Tosi S.p.A., Legnano. They run at 428·5 r.p.m. under a gross head ranging from 460 to 590 m. and each set discharges 14·8 cu. m. per sec. at full load.

The runner wheels are martensitic stainless-steel castings (13% chromium and 1% nickel), by George Fischer Ltd., Schaffhausen, and we are informed that on inspection after 12,000 hours running they showed no sign of wear. Each runner has 22 buckets which are cast integral with the wheel, and the overall diameter is 2·84 m.

The water supply to each runner is controlled by a separate spherical valve, and the supply pipe bifurcates into two 700 mm. bore branches to supply the two jets. The needles and nozzles, which have to withstand the abrasive action of sand contained in a jet emerging at 108 m. per sec., are of stainless steel of 18% chromium and 8% nickel content.

Good hydraulic conditions in the jet are obtained by the use of a self-contained needle assembly (Fig. 15) which is mounted concentrically in the body of the nozzle. Movement of the needle in accordance with the demands of the governor is achieved by regulating the pressure of water in a cylinder *a* immediately behind the needle, the back of the needle, in effect, acting as a piston. An overtaking gear *b*, controlled by the governor through a cam, ensures that the needle comes to rest in a position exactly corresponding to that of the governor. To limit the speed of movement of the needle to a safe value from the standpoint of water hammer, a backward extension of the needle carries a piston *c* moving between two chambers filled with oil, and transference of oil from one chamber to the other on movement of the needle can take place only through an adjustable restriction *d*. A water-to-oil accumulator *e* ensures that the oil pressure is always somewhat greater than that of the water in the nozzle.

At Santa Massenza the needles are set to close in 25 sec., corresponding to a pressure rise of 10%, and to open in 35 sec. The deflectors can divert the entire jet in 1½ sec.

The regulator unit forms a single assembly, as seen in Fig. 16, comprising oil pumps, cooler and storage chamber, actuator, relays and servomotor. Two oil pumps are provided, that in normal use being electrically driven; the standby pump is driven by a small Pelton wheel and comes into operation automatically if the main pump cuts out.

The actuator is of the accelero-tachometric type and is of an ingeniously simple design. Referring to Fig. 17, the actuator head contains a lower chamber *a* and an upper chamber *b* connected by a helical tube *c*. A watertight metal bellows *d* locates the bottom of the control rod *e*, which is acted upon by the control spring *f*.

The lower chamber *a* and the helical tube *c* are filled with mercury and the upper chamber *b* with water. As the head rotates, the centrifugal force causes a partial transference of the mercury from the lower to the upper chamber, thus forcing the control rod *e* upwards to an extent dependent on the speed of rotation and the setting of the spring *f*. In addition

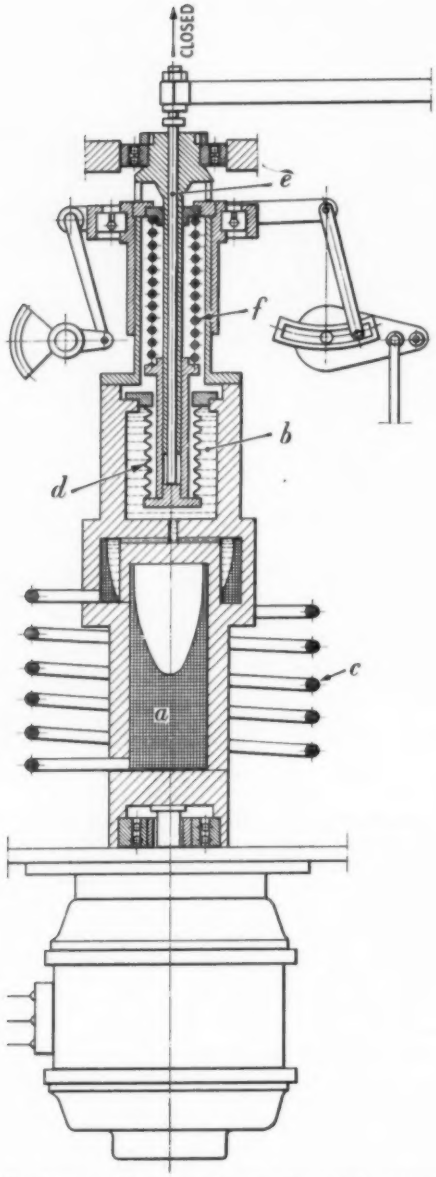


Fig. 17. Franco Tosi accelero-tachometric governor head

to this action, however, the helical tube is so handed that an acceleration of the head causes the mercury to travel up the helix and increase the pressure in the upper chamber, whereas a deceleration induces the reverse action. Thus the one operating medium—the mercury—responds at all times to the combined effects of speed and of acceleration, and, moreover, is virtually frictionless. The control spring *f* is provided with the usual adjustments for speed and speed droop.

A comprehensive system of safety trips introduced into the regulator circuit shuts down the turbine in the event of any occurrence likely to endanger operation. A braking jet comes into action for rapid shutdown.

To enable the set to operate efficiently while running for long periods on reduced load, the control is arranged so that one or more jets can be taken out of service, and if desired, the set can run at half load on one wheel, with the other removed for maintenance.

Against the wall alongside each generating set are two T.I.B.B. control and indicator boards. Fully automatic starting can be effected either from these boards or from the control room.

The 70 MVA Alternators

The four 70 MVA, 0·9 p.f., 50 c.p.s., 15 kV alternators were built by Tecnomasio Italiano Brown Boveri, and have been specially designed to meet the exacting electrical conditions under which they have to operate. Their dimensions were determined primarily by the flywheel effect needed to meet the hydraulic conditions and by the high reactive capacity called for by the electrical network.

A value of 1,350 ton m^2 was chosen for the flywheel effect, and this, at a normal speed of 428 r.p.m. and a runaway speed of 790 r.p.m., meant that materials of high mechanical qualities had to be used in the construction of the rotor. The total weight of each machine is 450 tons, of which 230 tons is in the rotor.

To simplify the steel castings and to ease the transport problem, the alternator shaft has been made in three pieces, consisting of a central spider, which has a hollow bore to transmit the torque without waste of material, and two shaft extensions which are spigoted to the spider and secured by fitted bolts. Steel core plates are shrunk on to the spider, and have dovetailed slots to carry cast-iron poles with laminated pole pieces. Slots in the pole pieces carry a damper winding, which is designed to enable the machine to function for short periods on full-load current with one phase open. Each rotor was completely assembled in the works and subjected to an overspeed test, after which it was dismantled for transport, the pole pieces, shaft extensions, and some of the core plates being removed.

The stator is split horizontally to facilitate transport and erection. Ventilation is on the closed-circuit system, the coolers being located in the basement immediately below each machine.

As already explained, Santa Massenza station has to supply three 220 kV systems, including the north-to-south Italian trunk line, and this may involve charging long lines under no-load conditions, and continuing to feed the network in the event of other stations tripping out. Under any of these abnormal conditions the voltage must remain stable and synchronism must be maintained. For these reasons the generators have been designed to possess special electrical characteristics, and special features have been introduced into the system of regulation. The short-circuit ratio of the generators is no less than 1·75, and this makes it possible to charge a 220 kV line 700 km. in length with one 70 MVA machine only.

The excitation circuit has a high "ceiling ratio" and an exceptionally high speed of response. It has been designed to maintain full excitation when the frequency drops from 50 to 45 c.p.s., or worse still, from 42 c.p.s. (at which value the plant can still function) to 38 c.p.s. To this end the main exciter, in the most

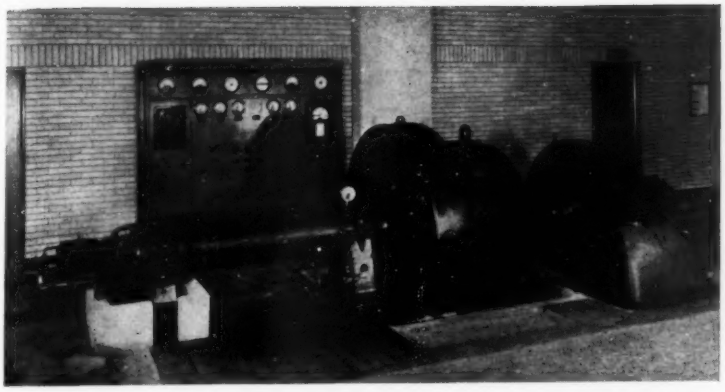


Fig. 18. Riva/T.I.B.B. 1,000 kW set with extension shaft for future Ponte Pià turbine

unfavourable conditions, can supply double its normal current at double its rated voltage for a period of one minute—a performance corresponding to four times its normal output. Its speed of response ($\Delta V/\Delta t$) is 3 volts per sec. as compared with values normally ranging from 0·5 to 2 volts per sec.

The auxiliary exciter is contained in the same frame as the main exciter, and in addition to the normal commutator it is provided with sliprings so that it can provide an emergency supply to the governor head in case the permanent-magnet generator breaks down. The latter machine, incidentally, is mounted on an extension of the exciter shaft. To minimise the effect of temperature changes on the excitation, a ballast resistance which is insensitive to temperature changes is introduced into the auxiliary-exciter field circuit. The auxiliary exciter has a special characteristic so that if the set attempts to overspeed, the generator voltage is built up steeply so as to load the machine in such a manner as to check its speed.

Working in conjunction with the exciter assembly is a rapid-action Brown-Boveri voltage regulator which provides for the generator to run under-excited and even with negative excitation. The generator has a reactive capacity of 55 MVAR at zero power factor and with a positive excitation of about 5% at 11·5 kV, and by means of the special regulating equipment it can be increased temporarily to 100 MVAR, the voltage remaining at 11·5 kV.

Other Generating Sets

The two 35 MVA generating sets are also double-wheel double-jet horizontal machines and have been designed to meet the same hydraulic and electrical conditions as the larger sets. The turbines for these machines were built by Costruzioni Meccaniche Riva and the alternators by Ansaldo-San Giorgio, S.p.A. These two sets are arranged so that they will drive the storage pumps which are to be installed eventually.

The 27 MVA vertical Francis machine forming Santa Massenza II was supplied complete by Ansaldo-San Giorgio, S.p.A.

For auxiliary services a 5 MVA 10 kV 1,000 r.p.m. horizontal set has been installed operating on water from Lake Molveno. It comprises a double-jet Pelton wheel supplied by De Pretto Escher Wyss, Schio, and an alternator by Soc. Naz. dell'Officine Savigliano, Turin. Space has been provided for the installation of a second set of similar capacity but supplied from Ponte Pià.

For low-voltage services a 1 MVA 500 V set has been installed consisting of a Riva single-jet Pelton turbine, supplied from Lake Molveno, and a T.I.B.B. alternator. This set is illustrated in Fig. 18, in which an extension shaft will be observed emerging from the alternator. This is to permit the eventual installation of a second turbine to be supplied from Ponte Pià, and it will then be possible to run this set from either the high-head or the low-head reservoir.

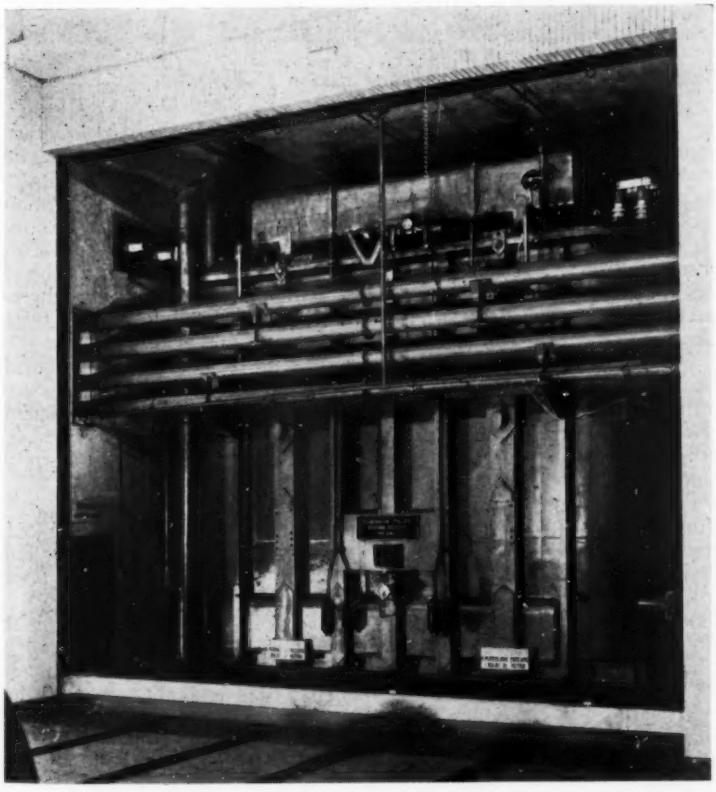


Fig. 19. One of the 70 MVA 15/240 kV transformers

Fig. 20. Santa Massenza outdoor switching station

Transformers, Cables and Switchyard

The main 70 MVA transformers, one of which can be seen in its cubicle in Fig. 19, are three-phase units stepping up from 15 to 240 kV. They are of the water-cooled type, the oil being pumped to coolers separate from the transformers. Each transformer is connected solidly to the busbars of the generator it serves, except in the case of the two 35 MVA generators, which share a single 70 MVA transformer, and on the high-voltage side a special cable box provides for connection to the Pirelli oil-filled cables.

For the 27 MVA Francis set the transformer arrangement is different because it will be used to couple in the supply from the future Nembia power station, which will be brought in at 60 kV. The 15 kV bars, in this case, are carried to the outdoor switchyard, where they are connected to a three-phase transformer bank which has three windings giving ratios of 15/60/220 kV. This bank consists of four T.I.B.B. single-phase radial-core units, one of which is a spare.

The 220 kV circuit breakers in the switchyard are of the minimum-oil quick-closure type manufactured by Società Adda of Lodi, Milan. They have a rupturing capacity of 3,500 MVA.

Electrical System and Control

The diagram of the main electrical circuits at Santa Massenza is given in Fig. 21. It will be seen that the Edison and the S.I.P. systems each have two 220 kV busbars, and any machine can be connected to either busbar of either system. Thus each system can be operated independently of the other, and can be supplied by any machines that it may be convenient to use. In addition, four lines, any of which can be connected to any busbar, are taken off to feed the Italian 220 kV system.

The connections for the 27 MVA set and the three-winding transformer to handle the 60 kV supply from Nembia will also be noted.

From the diagram for the auxiliary services it will be seen that both the 5 MVA and the 1 MVA sets are connected through transformers to a 20 kV system which interconnects with the auxiliary services of other power stations. There is also a transformer connection between the 10 kV and the 500 V bars served by the two machines.

The control annexe is in three floors, the top floor containing relays, protective gear, and so forth, not needed for the actual task of control, the centre floor being devoted to the control room proper, and the bottom floor to cables, voltage regulators, batteries and miscellaneous gear.

The control room, seen in Fig. 22, is a particularly handsome one, and has been laid out to render the handling of this large station as simple as possible. A curved control desk forms the main feature, and wall panels extend round the entire room except for an entrance door at each end and a central window behind the writing desk from which the machine

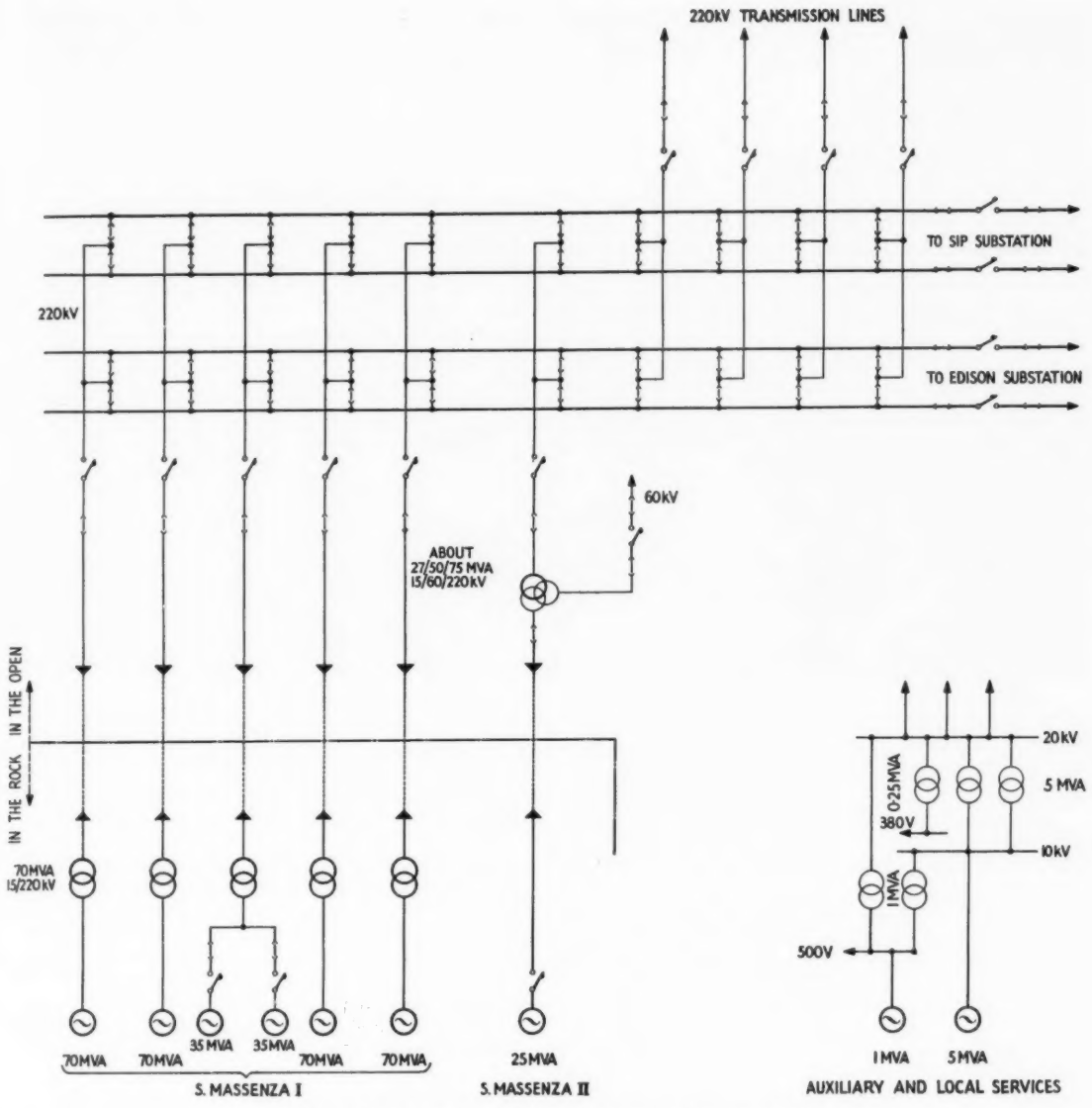


Fig. 21. Main circuit diagram of Santa Massenza station

room can be seen from a strategic position.

The control desk contains 13 panels and carries all the controls necessary for the actual operation of the seven main generating sets and the switchyard. The wall panels behind this desk carry the corresponding indicating and recording instruments, and in the centre of the wall is a large mimic diagram showing the state of all the main circuits in the station and the switchyard and also the condition of the hydraulic plant. At each point in the diagram representing a circuit breaker, isolator, or rotary valve, a green light shows that the circuit breaker or isolator is off or the valve closed, a steady red light shows that the electrical apparatus is closed or the hydraulic valve is open, and a flashing red light draws attention to a disparity between the position of the control and that of the apparatus controlled. Should the protective gear for any generating set or transformer come into action, a flashing yellow light will appear in the centre of the corresponding symbol on the mimic diagram. This board also carries indicators showing the water levels in the surge tanks of Santa Massenza I and II.

The auxiliary sets and circuits are controlled from wall panels, and other wall panels are given over to fault indicators and special control equipment. Altogether, there are 38 wall panels.

We would particularly draw attention to this "special control equipment," because some of the methods of control are unusual and of particular interest. In the first place the turbine panels in the machine hall and the corresponding panels on the desk in the control room are interconnected so that a set can be started either manually from the machine hall or automatically from the control room. For automatic control all relevant switches on the turbine panel must be changed over and all protective gear

Fig. 22. General view of Santa Massenza control room

must be correctly set, and the turbine operator retains the power of modifying the starting sequence in the event of any fault arising. In either method of starting, the control-room operator is able to follow the entire starting sequence from his instruments and indicators. Synchronising, also, can be performed automatically.

In view of the fact that Santa Massenza is a key station in three large 220 kV networks, a system of control has been introduced for practically the first time in Italy which it is believed will prove of increasing value in the regulation of large electrical systems. It is known as "power-frequency" regulation, and controls the output of the machines connected to the system according to the prevailing frequency and to a predetermined value of the output required from the station. The actual output can be measured either at the station or at a remote point on the transmission line, and the required output can be preset to any desired value. Any discrepancy between the actual and the preset loading, or between the actual and the standard frequency, makes an appropriate automatic adjustment to the governors of the machines connected to the system. Provision is also made to adjust the distribution of the load between the various machines and to maintain this distribution automatically. The system can also be applied to the control of the transfer of power between two distinct electrical networks.

A further unusual feature is a system of "time-frequency" regulation. This has been introduced to ensure that the clocks of the recording instruments operate on an accurate frequency of 50 c.p.s. The supply for these instruments is obtained from a 115 V alternator driven by a d.c. motor, the speed of which is controlled by a highly sensitive frequency controller. Should this motor-alternator set be taken out of action, the supply is derived from the 1 MVA house-service set through a transformer, and the time-frequency control is transferred to this machine.

The protective system for the main electrical equipment follows Brown-Boveri standard practice except that separate differential protection is available for the alternators and for the transformers and their associated cables.

The whole of the control equipment, including control room, turbine panels, protective and fault-indicator gear, and the special control systems just referred to, was supplied by Tecnomasio Italiano Brown Boveri.

Acknowledgments

We are happy to acknowledge our indebtedness to Società Idroelettrica Sarca-Molveno, and particularly to Dr. Ing. Claudio Marcello of Società Edison, and to Dr. Ing. Bruno Bonfioli of Società Idroelettrica Sarca-Molveno, for affording us facilities to visit Santa Massenza station and for placing all necessary information at our disposal for the preparation of these articles.

We also obtained much valuable technical information about the plant and equipment from Franco Tosi S.p.A. and Tecnomasio Italiano Brown Boveri during visits we paid to their works at Legnano and Milan respectively.

Constructional design and work management were carried out by the design and construction department of Società Idroelettrica Sarca-Molveno, under the direction of Ing. Angelo Testa and the supervision by a committee formed by Ing. Bruno Bonfioli of Sarca-Molveno, Ing. Giulio Gentile of SIP and Ing. Claudio Marcello of Edison.

Conference on Turbines and Pumps

The Fifth Hydraulic Conference organised by the Société Hydrotechnique de France was devoted to turbines and pumps. In this series of articles we review some of the information likely to be of value to the designer and operator, particularly that relating to materials of construction

PART ONE

THE Fifth Hydraulic Conference held by Société Hydrotechnique de France at Aix-En-Provence from 26–28 June was organised to review recent hydraulic turbine and pump developments. The subjects were posed in a typically logical French manner, as follows:—

Section I. *Turbine Developments and Their Influence on Civil Engineering*
- A. Developments in Materials (4 papers)
- B. Turbine Mechanism Developments (2 papers)
- C. Turbine Costs (1 paper)
- D. Influence of Turbine Developments on Civil Engineering (4 papers)

Section II. *Turbine Governors*
- A. General Governor Questions (5 papers)
- B. Modern Governor Design (3 papers)
- C. Special Problems (4 papers)

Section III. *Turbine Efficiency and Cavitation; Their Economic Influence on Equipment and Operation*
- A. Turbine Flow Investigations (5 papers)
- B. Determination of Turbine Characteristics (3 papers)
- C. Prediction of Prototype Performance (2 papers)

Section IV. *Turbine Operation*
- A. Turbine Wear (5 papers)
- B. Thrust Bearing Service Reliability (2 papers)
- C. Safety Arrangements (1 paper)
- D. Automatic Midget Power Stations (1 paper)

Section V. *Pump Turbines* (11 papers)

Section VI. *Pumps*
- A. Pump Development and Design (4 papers)
- B. Cavitation and Efficiency Characteristics (3 papers)
- C. Pump and Pumping Installation Operation (4 papers)
- D. Other Problems (2 papers)

Section VII. *Drilling Turbines* (4 papers)

As might be expected, many papers have a bearing on tidal power development and this was particularly noticeable in Section V dealing with axial-flow pump turbines which had their origin in the Rance tidal power scheme.

It is not possible to analyse, even briefly, all of the 70 papers, but apart from touching on the highlights of some of them, it seems better to give a co-ordinated review of those concerning turbine materials, because valuable data are disclosed which may assist hydroelectric engineers in the immediate future.

OPERATING CONDITIONS

The damage which is experienced in normal hydroelectric station operation may be accentuated by tidal conditions and can be classified as:—(i) Cavitation; (ii) Corrosion; (iii) Abrasion. The reports include operating and experimental data on abrasion damage and investigations on protection of metals against marine atmosphere and salt-water corrosion, but little is said about the magnitude of cavitation damage, although its importance is recognised in defining the metallurgical characteristics of materials, subject to one or more of the conditions specified.

Cavitation Metallurgy

Cavitation arises from turbine design whereas corrosion and abrasion are chemical and physical effects caused by the water itself. It is therefore appropriate to introduce Weil–Couly & Kermabon's outstanding metallographic studies of cavitated runner material, from which they derive a percussion theory for cavitation damage and deduce the physical characteristics which an alloy should satisfy to resist it. This paper endeavours to correlate fatigue theory in terms of repetitive energy cycles absorbed by intercrystalline deformation and sliding along the crystal planes. The period preceding damage starts grain-joint fissures which are propagated internally, and this intercrystalline and subsequent transcrystalline action is coupled with corrosion and galvanic phenomena.

Metallographic examination of cavitated material indicates at:—

(i) 100–200 magnification non-uniform wear showing the granular structure. Damage appears as if each grain or grain group is independent, some having resisted and others having disappeared.

(ii) 500–1,500 magnification:—

(a) Intergranular cracks in one or more grains with cavities apparently damaged by chemical or electro-chemical corrosion.

(b) Transgranular cracks perpendicular to the cavity face.

The high-iron-content cupro-aluminium alloys show iron and aluminium nodules. Microphotographs of 5% Fe specimens show that the junction of a crack and an iron nodule coincides with a cavity or start of a cavity.

Magnification	*Observations*
100	Crack becomes a corrosion zone
200	Visibly corroded crack
1,000	Intergranular crack meeting two iron nodules and producing a couple.

These observations suggest mechanically initiated damage accelerated by fatigue and corrosion and elimination of the metal grains by:—

TABLE I. CUPRO-ALUMINIUM ALLOYS: RANGES OF PHYSICAL AND CHEMICAL PROPERTIES AND CAVITATION RESISTANCE

Grade	Chemical Analysis				Mechanical Characteristics				Grain Structure	Cavitation Resistance Turbine Operation	Fatigue Strength Kg/sq. mm.	
	Al	Mn	Fe	Ni	Ultimate Strength Kg/sq. mm. *R*	Elastic Limit Kg/sq. mm. *E'*	Elongation % *A*	Resilience Kg.m./sq. cm. *KUF*			Air	Sea Water
A	8·0	4·0	—	—	45	18	40	9	Large elongated grains	Good	Not given	
	9·0	6·0	—	—	50	20	45					
B	9·0	1·0	1·0	—	45	20	12	3	Average-size rounded grains	Better than A	Not given	
	10·0	—	2·0	—	50	22	15					
C	9·0	0·5	2·0	4·0	55	23	12	3	Fine elongated grains with treatment to reduce dimensions	Better than A and B	Not given	
	10·0	1·5	3·0	6·0	65	20	18	5				
Kermabon and Mosse Paper	9·7	0·5	2·8	4·5	55	23	12	3	—	—	18	14
	—	—	—	—	65	30	18	5				

(i) Joint displacements transformed into relatively important intergranular cracks.
(ii) Percussion-effect stress variation due to the discontinuous nature of cavitation causing transgranular cracks along the cleavage planes.
(iii) Galvanic couples in the intergranular cracks or zones of final cooling during solidification where there are chemical heterogeneities, such as low-fusion-point eutectics, oxides and segregation.

The metallurgical characteristics of cavitation-resisting alloys are therefore:—

(a) Homogeneous non-oxidising metals which will delay formation of local cells and electrochemical corrosion.
(b) Inter- and transgranular strength to withstand crack formation.

A qualitative mathematical analysis based on granular absorption of bubble percussion energy at the instant of collapse accompanied by intergranular cement and grain heat release leads to the expression:—

$$(1-e^2)\frac{MM'}{M+M'}V_o^2 < \text{maximum grain or intergranular cement deformation energy}$$

where M & M' are striking and struck masses

V_o V_1 Velocity of striking mass before and after impact.

$$e = V_1/V_o$$

Where $MM'/(M+M')$ is small the alloy grains have small mass and:—

(i) Maximum grain deformation energy under discontinuous cavitation demands an alloy with high fatigue strength in water.
(ii) Maximum energy absorption by the intergranular cement (which seems important because intergranular cracks were observed in all cases and are the origin of corrosion) requires elimination of grain-joint heterogeneities, especially precipitations of fragile elements such as low-fusion-point ternary eutectics.

Briefly, therefore, optimum cavitation resistance requires:—

(a) High coefficient of elasticity
(b) Fine grain structure
(c) Absence of isolated chemical heterogeneities
(d) Corrosion resistance
(e) High fatigue strength in water
(f) Absence of impurities and precipitation in the grain joints
(g) Absence of microscopic defects and zones of chemical impurities at points of low mechanical strength.

The paper finishes with:—

(i) A reference to three cupro-aluminium alloys developed for cavitation resistance. The characteristics are given in Table I.
(ii) A plea for more searching metallurgical investigations using the electron microscope.

Fatigue and Corrosion

Mechanical fatigue is closely related to cavitation resistance, and besides ultimate strength, elastic limit and the runner operating stresses, tidal-power development introduces sea-water corrosion problems. Papers concerned with the stainless steels refer to these conditions and mention research on 16/4 and 17/3 structurally hardened martensitic varieties.

The electrochemical corrosion reactions are little understood. Castro, Gueussier & Tricot deal with surface treatment and laboratory results on three recently developed stainless steels, (Table II) which they state must be confirmed in service. They con-

TABLE II. STAINLESS-STEEL CORROSION-FATIGUE TESTS: LABORATORY RESULTS

Grade of Cast Stainless Steel		13/2 Martensitic Cr Ni				Martensitic Structurally Hardened with Cu Addition	Austeno-Ferritic
Chemical Analysis—	%						
Carbon	C	0·10				0·05	0·08
Silicon	Si	0·31				0·30	0·30
Manganese	Mn	0·65				0·43	0·56
Nickel	Ni	1·90				3·80	7·50
Chromium	Cr	13·20				16·10	23·70
Molybdenum	Mo	—				—	2·00
Copper	Cu	—				2·50	0·55
Sulphur	S	0·018				0·016	0·019
Phosphorous	P	0·025				0·012	0·023
Heat Treatment of Test Pieces		Tempering				Tempering	Hyper-tempering
Mechanical Characteristics—							
Ultimate Strength	Kg/sq. mm.	79				75	61
Elastic Limit	Kg/sq. mm.	62				62	42
Elongation	%	16				15·5	28
Resilience (Mean)	Kg.m/sq. cm.	6·85				9·4	13·1
Surface Treatment		A Standard Finish	B 50% HCl 10 sec. washed and undried	C 10% HNO_3 10 min. at 60°C and 20g/litre Na F washed and dried or 10% HNO_3 48 hours at 30°C washed and dried	D C followed by B	A Standard Finish	A Standard Finish
Roughness Microns—							
Air	Mean	1	—	18–24	—		
	Maximum	3	—	30–42	—		
Water pH 6·7	Mean	3	3–5	15–30	12–18		
	Maximum	6	10–12	42–54	36–50		
Sea Water pH 5·5	Mean	3–6	3–6	12–30	18–30		
	Maximum	35	12–18	48–60	36–75		
Fatigue Strength	Kg/sq. mm.						
Air		30	—	27	—	37	17
Water pH 6·7		24	22	17	17	29	14
Sea Water pH 5·5		11	9	9	8	17	11

TABLE III. MODEL TURBINE CORROSION TESTS IN SEA WATER: RESULTS CLASSIFIED IN ORDER OF MERIT

Material	Chemical Analysis				Conclusions after 3000 hours Machine Operation	Continuous Immersion
	Cr	Ni	Cu	Mo		
1. High-strength Cu/Al Alloy (A)	—	—	—	—	—	—
2. Structurally Hardened Martensitic Steel	17	4	4	—	Highly resistant if perfectly cast	Rust spots from casting defects.
3. Austenoferritic Steel	23	8	—	2·5	Highly resistant if perfectly free from machine-tool steel particles	No traces of rust.
4. ,,	20	7·5	—	2·5		
5. High-strength Cu/Al Alloy (B)	—	—	—	—	—	—
6. Martensitic Steel	13	2	—	—	Moderate resistance	Deeply corroded.
7. Semistainless Steel	4	1	—	—	Corrosion progresses rapidly from beginning as for ordinary steels	—

clude that the fatigue limit is reduced by:—

(i) 18–22% in fresh and 47–63% in sea water
(ii) Increased surface roughness due to corrosion. The initial surface microgeometry predominates but is less important in sea water.

Rather inconclusive preliminary studies by Defranoux, Changarnier and Legrand outline electrochemical methods of determining the factors in seawater corrosion using polarisation curves including the influence of:—

(i) Differential aeration
(ii) Water movement
(iii) Role of micro-organisms and fouling
(iv) Galvanic corrosion arising from couples due to:—
  (a) Inherent defects in the metal such as local differences in the crystalline structure and inclusions
  (b) Shape and method of construction and their elimination by cathodic protection.

Simple weight-loss tests on small samples do not correspond to experience, and Prof. R. Gibrat, the Reporter for Group V, partially brings this into focus by reference to the simplified scale model of the 'Rance' bulb units used to test bare and protected metal in sea water, excluding cavitation effects. The test cycle on the machine was:—

(a) Running Immersed 8 days
(b) Shutdown Saline atmosphere 8 days
(c) Dismantling Every 21 days

from which the materials were classified as in Table III. This shows that continuous submersion is the more severe test because in the test machine ordinary and semi-stainless steels behave as soluble anodes to protect cathodically the highly alloyed components. The normal structural parts of a turbine must not corrode, and it is concluded that while cathodic protection seems essential, its proper application requires further investigations.

Paints for Tidal Conditions

Prof. Gibrat described the paint tests made in connection with tidal power schemes for spray, continuous and discontinuous immersion in sea water since 1955, which are summarised below.

Basic Classification	*1955 Spray Tests % undamaged*
Oleosynthetics	16
Glycerophthalics	16
Chlorinated Rubber	33
Epicote	33
Vinylics	75

TABLE IV.—PAINT TESTS FOR TIDAL CONDITIONS, 1957

Basic classification	1957 spray tests		Tidal range tests	Continuous submersion	Anti-fouling resistance
	Exposure months	Remarks			
Bituminous	3	Bad peeling	Little resistance		
Oleosynthetics	—	—			
Glycerophthalics	3	Punctured			
Rubber based	6	Punctured cathodic blisters			
Zinc based	—	—	—	—	Good but may wear rapidly
Isocyanate	—	Good	Good results		
Epoxide (Araldite)	8	as new			
Vinylic	—	Poor to excellent according to quality			Two samples excellent
Cu based vinylic	—	—	—	—	Excellent
Metallisation	—	—	—	Good	

Subsequent results with more varied conditions up to 1957 are classified in Table IV.

Zinc coatings tested under tidal and continuous submersion conditions, with and without cathodic protection, showed:—

(i) Dry blistering causing exfoliation of layers and with steel due to defective adherence.
(ii) Metallisation subject to localised pitting with white-powder-filled cavities forming seat of separation.
(iii) Thick layers to be more effective.

The vinylic paints depend greatly on quality but:—

(a) They retain high electrical resistance which collapses with appearance of blisters.
(b) They appear compatible with cathodic protection which is less effective with inert types.
(c) Anti-fouling protection is necessary. The copper-based types give good results.
(d) Liable to blistering and loss of adherence in zones of small thickness.
(e) When tested in the scale-model machine the internal surfaces blistered six times as quickly as external finishes.

Cathodic protection has to be used with care because the stability of certain paints, when submerged, is bad and the coating can be destroyed by sudden release of hydrogen or chemical reactions with the electrolyte. The laboratory tests correlated satisfactorily with estuary tests, which were less easily controlled.

Reference was made to Surrel's theory based on observed vinylic paint blistering at the plate edges while the priming coats held perfectly. This suggests that the thin steel/paint face resists water penetration and remains undamaged while surface layers swell and fail by interface tension or shearing, indicating thin layers and few coats are essential.

Clearly the painting problem has a long way to go before it is completely solved for composite structures.

Abrasion

The reports on abrasion were related to Alpine and African rivers and not to estuarine conditions where this form of damage might be added to those already mentioned.

For long-term operating efficiency, loss of waterway shape must be avoided, since energy loss by abnormal wear may be 10–20 times the replacement cost of the component concerned. This is the technical and economic theme of Ferry Willm & Thouvenin's paper. The thermodynamic-loss measurement method was used for periodic checking of machine condition. Its use is limited to heads exceeding 100 m. although one paper indicates possibilities below this level.

Abrasion of Pelton and Francis turbines will be considered separately because construction differences introduce distinct problems.

PELTON TURBINES

Bellamy and Lefrancois report operating experience at Darguinah in Algeria. The plant consists of two four-jet 46,000 h.p. vertical Pelton turbines using water containing 100 g. per litre of dry angular material with a hardness of 7 on Mohr's scale. Alpine water may contain 30 g. per litre of more aggressive suspended matter.

Severe injector abrasion occurred during commissioning which coincided with a flood carrying a heavy solid charge. Two groups of figures are given:—

Injector material	*Duration of operation (hours)*	*Flood charge*
1. Original 13% Cr. 0·3% C. Brinell hardness 400 ...	300 1170 1250	Heavy
2. Repaired with stainless Cr. overlay 0·05 mm. thick	740 1190 2600	Heavy but lighter than 1

The needles and nozzles were redesigned in small light-weight pieces to facilitate dismantling and replacement in eight hours but subsequent tests with different materials (Table V) are informative.

The conclusions reached were that:—

(i) Although no weight losses were taken and the degrees of wear were different, the hard chrome coverings were best.
(ii) The life depends on the thickness.
(iii) Wear diminishes with hardness but crystalline structure also has some influence.

TABLE V. DARGUINAH POWER STATION: INJECTOR ABRASION COMPARISON ON TWO FOUR-JET 46,000 h.p. PELTON TURBINES

Test	Material	Thickness mm.	Rockwell Hardness	Total Operating Hours	Hours Operation with Charged Water *H*	Energy Generated MWh *E*	Solids Discharged *v* million cu.m.	*Hv/E*
A	13% Cr 2% Stainless Steel	—	60/61	2400 6968	539 1468	9·79 27·43	0·72 1·38	39·9 71·8
B	High Chrome Steel R:200 kg/mm-Nitrided Surface	0·8–1·0	60	2606 848	750 208	10·30 3·64	0·40 0·40	28·2 22·3
C	Ordinary Steel 13% Cr 2% C Hard Chrome Covered	0·06	—	4795 855	455 272	6·96 5·39	0·23 0·47	15·5 22·5
D	Semi-hard Steel 13% Cr 2% C Hard Chrome Covered	0·5–0·6	—	5764 3617	840 620	15·74 12·20	1·31 1·82	69·6 88·7
E	Ordinary Steel with Ni Cr Mo Overlay	—	—	2507 2911 2029	214 381 393	3·77 6·42 5·94	0·161 0·211 0·075	9·1 13·4 4·7

TABLE VI. PERRY, WILLM AND THOUVENIN TESTS ON PELTON TURBINES

(A) *Injectors*:

Material		Lightly Alloyed Nickel-Chrome Steel	High-speed Tungsten-Vanadium Steel
Chemical Analysis—			
Carbon	C	0·4	0·8
Chromium	Cr	1·5	4·5
Nickel	Ni	4·0	0·3
Molybdenum	Mo	0·5	0·7
Manganese	Mn	—	0·3
Vanadium	Va	—	1·3
Tungsten	W	—	18·5
Brinnell Hardness		534	650
Operating Time	hours	560	1100
Volume Lost	cu.cm.	250	—
% Efficiency Loss—			
50% load		7·0	2·5
100% load		6·0	0·5
% per 1000 hours operation		4·2–9·0	0·7–1·5
Replacement Period	hours	150–250	500–800

(B) *Runners*: Tests made with new injectors.

Station	Arvan	Argentiers
Hours of Operation	5400	4000
% Efficiency Loss—		
50% load	2·0	3·0
100% load	0·5	0·5

(iv) Erosion is accompanied by corrosion aggravated by cavitation.

(v) Tungsten-carbide cladding costs were prohibitive although a test on an auxiliary machine gave 11,700 hours' operation.

(vi) Experience is the only guide to choice of materials.

Ferry, Willm & Thouvenin quote test results, some of which are given in Table VI, on Peltons using Alpine water carrying 30 g. per litre of solid matter from which it is clear that:—

(a) Efficiency is influenced by jet deformation caused by loss of needle and nozzle shape. In one case the drop in efficiency was 6% in 600 hours.

(b) Needle wear affects partial-load efficiency whereas nozzle wear predominates near nominal load.

(c) Abrasion is less serious for runners.

The causes of loss of efficiency are:—

TABLE VII. FERRY, WILLM and THOUVENIN RESULTS FROM FRANCIS TURBINES

Station		Monistrol	Avrieux	Courbaisse	Beaufort
Purpose of Measurement		Test	Test	Perfor	mance
Output	MW	5·0	3·3	13·0	6·5
Head	m.	195	100	128	250
Hours Operation		—	—	20,000	5,400
Labyrinth Length	mm.	50	100	—	—
Leakage q_0	litres/sec.	60	36	—	—
Diameter	m.	1·03	1·00	—	—
Peripheral Velocity	m./sec.	41·0	37·7	—	—
Mechanical Loss	kW	55	30	—	—
Clearances—					
Test Range	mm.	0·7–1·0	0·75–2·0	—	—
Original/Final	mm.	—	—	1·0/5·0	—
% *Loss Efficiency*—					
50% load		—	—	10·0	—
100% load		—	—	3·0	—
Mean Loss		—	—	5·0	3·0
Overall/mm.		4·0	2·0	1·0	—

(a) Bucket splitter regression and jet dispersion.

(b) Bucket outcut profile and exit angles modifications.

(c) Bucket surface degradation.

The influence of bucket profile is illustrated by the following figures:—

Comparison	*Smooth and 500 micron surfaces*	*Sharp-edged and 6 mm. rounded splitter*
Efficiency difference		
50% load	1·0	0·5
100% load	4·0	—

The economic runner-repair period is not fixed by efficiency loss alone but often by mechanical strength and safety, notably by bucket cracking.

Typical figures for repair costs and periods are:—

Component	*Runner*	*Injectors*
Annual loss of efficiency, % ...	0·5	0·7–1·5
Repair costs/energy value, % ...	1·0–3·0	0·20
Repair period	10–15,000	1000

FRANCIS TURBINES

Ferry, Willm & Thouvenin's systematic thermodynamic tests, including replacement of worn parts in high-head Francis units, show that progressive labyrinth deterioration is the principal cause of efficiency loss and that:—

(i) Wear is concentrated on the fixed parts subjected to the centrifugal effect of abrasive particles.

(ii) Friction losses by runner braking remain practically constant and that leakage losses due to increased clearances predominate.

Without careful maintenance this can reach 0·5% per 1,000 hours which emphasises the need for special labyrinths, and Bouquier's paper, which describes a throttled type giving balanced leakage and viscous friction losses, recommends:—

(a) Self-lubricating bearings and great structural rigidity to reduce clearances.

(b) Diameter reduction to decrease relative velocitities and leakage areas.

(c) Materials such as surface-hardened steels, hard chromium electrolytic linings and possibly plastics or synthetic rubber to increase the replacement period to 2–3 years.

The importance of proper clearance can be seen from:—

$$q = q_o \, 0{\cdot}7^{\,(1-x)} \, a^{3/2}$$

where q_o is full-load leakage

a clearance in mm.

x is fraction of full load

Ferry, Willm and Thouvenin quote some results, abstracted in Table VII, to illustrate this point.

Francis runner wear is by abrasion and cavitation, and relative to Peltons:—

(i) Fatigue is less important unless alternating stresses are set up by blade vibration, because the torque is nearly constant.

(ii) Abrasion is less harmful because of lower velocities but nevertheless causes appreciable wear which affects maintenance of hydraulic shape. There is no indication of the influence of shape changes on efficiency which would locate surface treatment but abrasion may cause deterioration at the:

(a) Discharge edges which modify flow downstream of the runner and consequently draft-tube and overall efficiency.

(Continued on page 389)

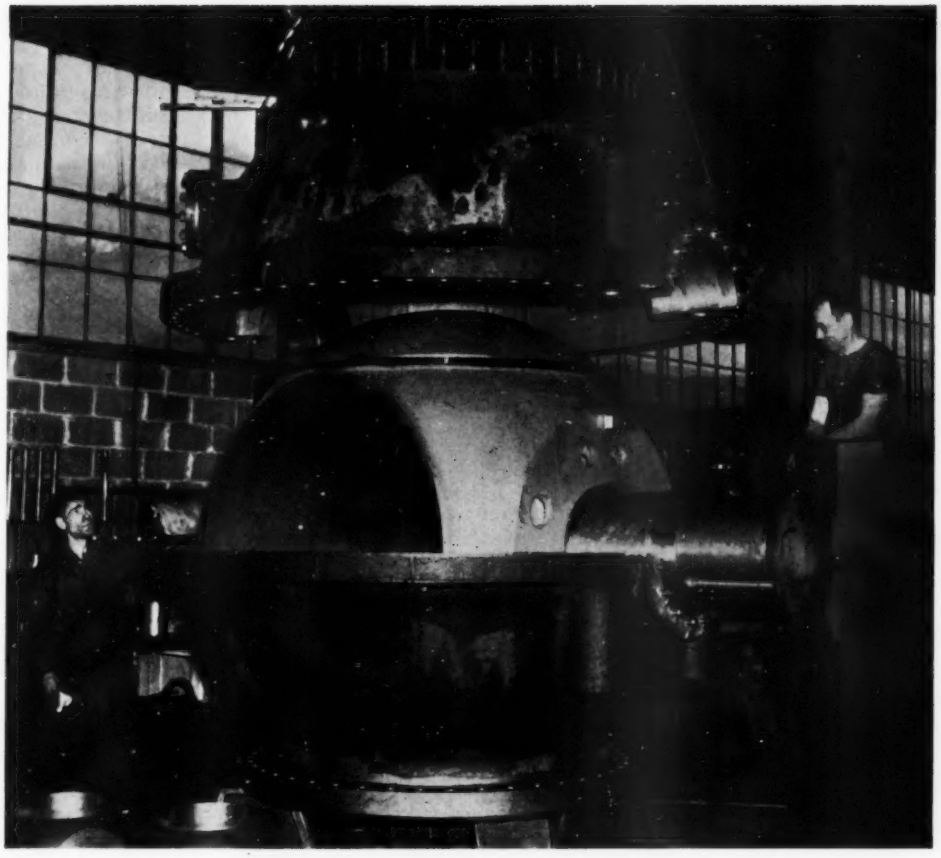


Fig. 1. Shop assembly of 54 in. spherical valve

Large Hydro-Electric Valves: Some Recent Applications

The substance of a paper presented to the Hydraulic Power Section, Eastern Zone, of the Canadian Electrical Association by L. M. BOYD*

IN the layout of a hydro-electric generating station it is not unusual to find a turbine shut-off valve above the turbine case. Dependent upon the head and type of equipment in question, the cost of the valve will vary roughly between 20% to 35% of the cost of the turbine. This is a substantial part of the plant investment and yet the value of the valve is primarily negative; it produces no revenue and adds neither to the power output nor the efficiency of the turbine. On the contrary, it is too often a troublesome annoyance, plaguing operating and maintenance men alike. Instances can be cited where expensive valves have been concreted securely and permanently into the open position; or again where a valve is not trusted sufficiently to permit men to enter the case without the precaution of dropping the head gates, thus nullifying the main purpose of the valve.

This, of course, is not a fair picture of hydro-electric valves. These valves in large numbers are giving long and trouble-free service and as such are receiving little publicity, but it does point to the care needed in the proper selection, design and application of valves. In this paper it is proposed to cover briefly some of these applications, designs and problems.

For purposes of this review, valves may be considered under two headings: type of application and

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type of design. Let us first consider application.

In the hydro-electric industry large valves are found in two main applications, as penstock valves and for turbine shut-off service. A third application, the free discharge valve, fills an important but somewhat specialised need and is omitted from this paper only in the interests of brevity.

A penstock valve may be defined as one set in the penstock usually at some remote position from the turbine. When the valve is placed in a divided penstock, usually just below the "Y," its purpose is apparent. The closing of one of the valves will permit inspection and servicing of the turbine or turbines fed by its branch without the loss of power from the units fed by the other branches. In addition these valves are often considered as emergency closing valves to protect the power house in case of a rupture in the penstock. They are usually designed to withstand the forces due to closing under some increase over full flow and to close automatically when this flow is reached.

When the penstock valve is situated in a single penstock its value is not as apparent. Aside from the above function of emergency service, its value can be considered to be the time saved in unwatering the penstock or tunnel above the valve when the units below are shut down for inspection or servicing.

A turbine shut-off valve is one placed immediately in front of the turbine case. Its purpose is the same as that ascribed above to penstock valves, namely, for emergency protection of the case and for inspection or maintenance of the turbine without taking adjacent wheels out of service. In addition, it may be used to reduce the wear of the wicket gates when the wheel is shut down for extended periods. This application is increasing with the increased use of turbines for peaking power instead of base load.

Types of valve

Let us now consider the valves from the point of view of design. We will examine in some detail the follower-ring gate valve, the Johnson valve, the butterfly valve, and the spherical valve. The follower-ring gate and the Johnson valves are receiving very little consideration today for new applications, but they will still be found in many stations and are included in this paper to round off the review and permit comparisons.

The follower-ring gate valve is used primarily in turbine shut-off service under medium to high head. It is basically a gate valve modified by an extension of the body downward away from the bonnet to provide space for an extension to the valve disc carrying a bore equal to the bore of the body. When the valve is in the open position the gap between the seats found in conventional gate valves is filled by the disc extension. This eliminates the cause of the high head losses associated with the conventional gate valve. By proportioning the valve as a cylinder in both upper and lower bonnets, it is readily designed for high pressure. One great objection to the follower-ring gate valve is the space occupied in the power house. This, with high friction and resultant wear, and the high cost associated with its bulk has placed the follower-ring gate valve in disfavour in recent years.

The Johnson valve is familiar to most of us. It consists of a streamlined plug moving axially in the penstock within a body which is essentially a swelling of the penstock proper. Movement of the plug actuated by controlled hydraulic unbalance, shuts off or frees the flow of water, The Johnson valve requires little head room although its length necessitates a large valve chamber. Its seating characteristics are moderately good and its head losses are low. It performs exceptionally well under the throttling action required in emergency shut downs. It has come into disfavour because of its high costs and tendency to be erratic in operation. Wear and difficulty of access for maintenance are also disadvantages. It found application in turbine shut-off service and extensively in city waterworks.

The butterfly valve consists essentially of a lens-shaped disc pivoted on trunnions within a cylindrical body. A 90° movement of the disc presents to the flow either a streamlined shape in the centre of the penstock or a flat disc completely filling the body. Its advantages are a minimum of power-house space required for application, low mechanical friction on easily lubricated trunnions and associated freedom from wear, reliable operation and low cost. In many applications these points easily override the disadvantages of leakage and head loss and have made it by far the most popular valve for penstock service and turbine shut-off service under low and medium heads. Since this valve today may be considered as almost "the standard of the trade" we will return again to a consideration of the disadvantages of head loss and leakage.

The spherical valve is a relative newcomer in the field and its description is for some reason puzzling (Fig. 1). In its simplest form it consists of a spherical plug traversed by a cylinder of full valve size and supported on two trunnions in a spherically shaped body. A 90° movement of the plug on its trunnions presents to the flow of water in the penstock either the full-size bore or the blank spherical surface of the plug. A movable seat in the body, usually hydraulically actuated, engages a seat on the plug rendering the valve the most leak-proof in the industry.

Compared to the butterfly valve the objections to the spherical valve are cost and the complications of control necessarily associated with the movable seat. Since this valve is achieving greater recognition every day, we will return later to a consideration of these controls. Outstanding advantages of the spherical valve are compact mounting dimensions, exceptionally low head loss, low mechanical friction on lubricated surfaces and associated freedom from wear. The ease of arrangement for double seats which makes it virtually valve and guard valve combined, the accessibility of seats for replacement, and above all its very definite superiority in freedom from leakage make this valve the increasing favourite for medium and high-head application.

The Butterfly Valve

One of the most controversial and disturbing parts of the butterfly valve is the seat and associated leakage. The obvious advantages of the butterfly valve are so great that it has been and is finding great favour in spite of this alleged defect. A review of the requirements of leakage may resolve the problem to its proper perspective. In an early part of this paper we found that the application of butterfly valves cover emergency protection, shut-off for inspection and maintenance, and protection of the wicket gates during

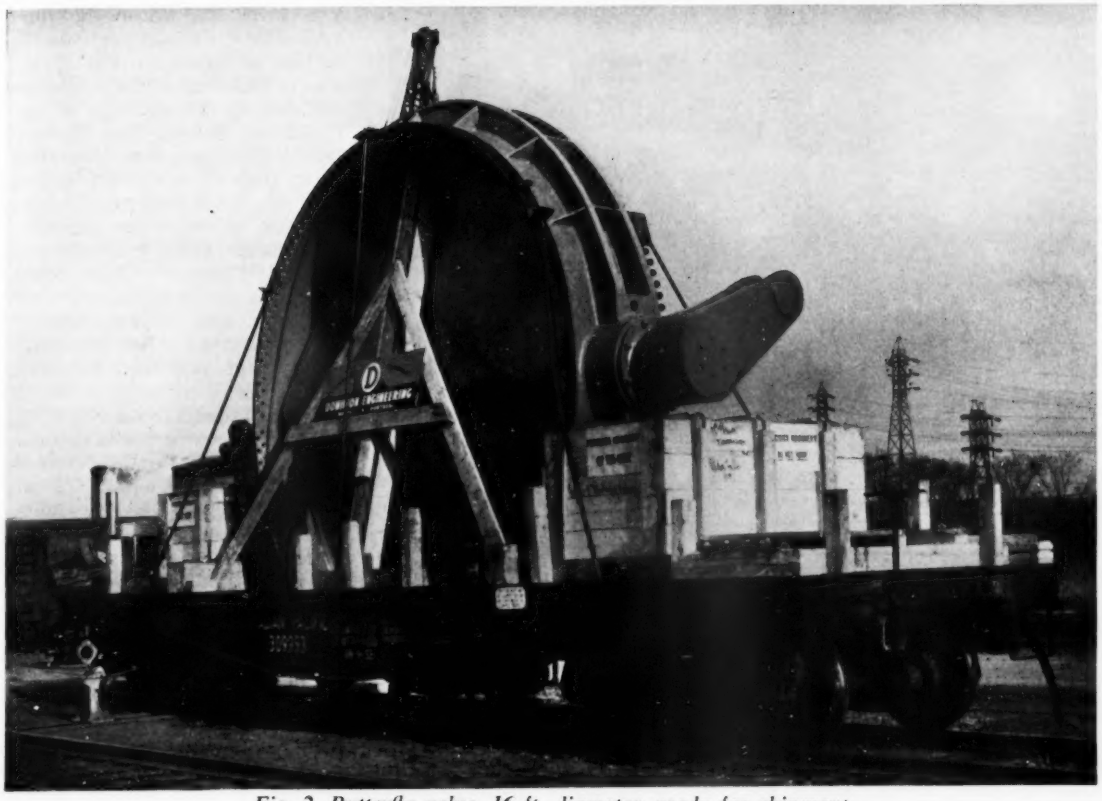


Fig. 2. Butterfly valve, 16 ft. diameter, ready for shipment

periods when the unit is off the line. Leakage is of little significance in the first two applications if kept within reasonable bounds but assumes first importance in the third if the wear taken off the wicket gates is not to be merely transferred to the valve seats.

The key to our acceptance in the first two applications is, of course, the words "reasonable limits." In emergency service leakage causes little concern where the valve's function is complete if the flow is reduced to proportions which will bring the plant under control or which will cause no significant damage until more deliberately functioning equipment can be closed down.

This criterion of leakage, of course, is not acceptable for inspection or maintenance of the turbine. Leakage in this case is objectionable if it prevents access to the case or interferes with the efficient performance of the maintenance or inspection in hand. The maximum leakage for this service may then be specified as that which can be taken care of by the casing drain with an adequate margin. Those of us who have entered cases with penstock pressure on the valve well know the instinctive association of leakage with the danger of failure. However, some reflection should assure us that there is no necessary association between leakage and strength, and leakage within reasonable limits, as defined above, should find acceptance.

When it comes to protection of the turbine gates, leakage becomes even more critical. As said above, leakage at the valve will merely transfer the wear from the gates to the seats of the valve itself. In these applications leakage must be reduced to a minimum and absolute tightness is desirable.

Before we describe some of the designs evolved over the past to meet these demands, an analysis of the action of a butterfly valve under pressure will be helpful. As pressure strains the valve, the body distorts radially away from the disc about its full periphery while the disc deflects as a cantilever on both sides of the trunnions. Any satisfactory design of seat must be capable of compensating for both these distortions.

An early design had a cylindrical body bore engaging a cylindrically turned disc set at an angle of approximately 80°. Distortion of the disc could be accommodated to some degree by torquing the disc further closed but it could not correct for the swelling of the body at the trunnions and leakage was heavy in this area.

An improvement over this was the addition of an adjustable seat on the disc which could be jacked out by adjusting screws. This went a long way to correct the leakage at the trunnions, but added a new problem. Due to the fact that the disc seating faces were nearly parallel to the body at the trunnions the valve had a pronounced tendency to jam in the closed position, especially if pressure was reduced on a tightly adjusted valve. This problem was overcome by the addition of separate body seat rings and by a trick in machining procedure. True conical seating was achieved around the full periphery permitting full adjustment and at the same time providing taper seats to assist in pulling off when opening. This arrange-

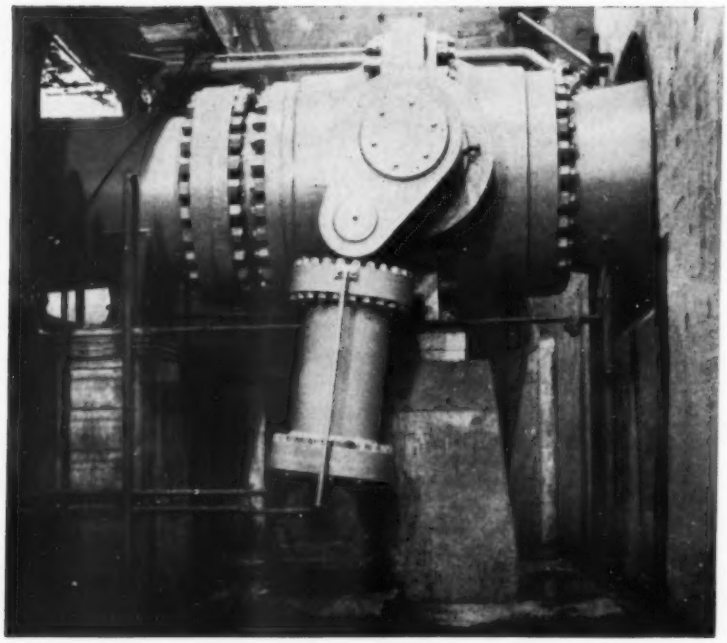


Fig. 3. 51 in. spherical valve installed at site

ment necessitated entering the case to permit adjustment and, as an alternative, radial adjustment was provided in the body seat rings accessible from outside the body. At first glance the outer adjustment will have appeal from the viewpoints of safety and convenience, but the inner adjustment remains the favourite because it permits direct approach to the leakage and also makes possible the addition of special pads at the trunnions where tightness is exceedingly difficult to achieve under other methods. Properly adjusted, this method will achieve surprising freedom from leakage and is the arrangement most in demand for heads up to approximately 300 ft. Equipped with stainless seats this valve is performing excellent service in many applications over this range.

For higher heads the inevitable leakage, no matter how small, will tend to increase with wire drawing and unless used for only brief periods of shut-down other methods should be sought. The one finding increasing consideration today for medium heads and for applications up to that suitable for the spherical valve is the inflatable-body rubber seat. There is a natural reluctance for engineers to rely on rubber in an elastic application for services with the long life expected from turbines and associated equipment. The design is by no means new but was installed by Dominion as long ago as 1929 and its acceptance is shown by repeat orders from this purchaser in 1937 and 1950. One objection to this design is the need for interlocking the separate controls for valve-seat and valve-disc operation. This problem is shared with the controls of the spherical valve and will be considered in detail with the description of that valve.

Before leaving butterfly-valve seats, a word must be said about adjustment. The manufacturer's setting of the valve seats cannot be expected to be retained through shipping, and must be reset in the field. Even if a valve shipped in the fully assembled condition survives the racking of handling, it is almost always distorted in the setting up and joining into position at site. Especially in high-head applications leakage in a poorly adjusted valve may be so severe that a man cannot be expected to enter the case to make the necessary adjustments. When this occurs we have no alternative but to drop the head in the penstock until distortion and resulting leakage are reduced to a bearable limit. Adjustment can then be made concurrent with raising of the head until the full head is reached. Two steps can be taken to minimise this effort. First, by controlling the initial watering of the penstock in easy stages accompanied by adjustment as described above, and second, to offset the lower edge of the unstressed disc from its mating seats by a calculable amount which will approximate to the distortion to be expected under full load. While this cannot be expected to achieve an acceptable tightness without further adjustment, it is usually sufficient to permit entry into the case to make the final setting. The manufacturer should be consulted for figures for the initial seat setting.

Head losses in a valve should be an important consideration in its selection. These losses through a butterfly valve with constant-bore body may be estimated quite accurately by applying a coefficient to recovery of the velocity head as the water flows past the restriction caused by the disc. For valves with well-shaped discs the coefficient of head loss may be taken as 25% of the recovered head. Fortunately, this loss can be reduced by the use of a converging section on the downstream side of the disc. The case entrance is usually smaller than the penstock diameter, and if advantage is taken of this to choke the flow on the downstream half of the disc, the head loss can be reduced to little more than friction over the valve surfaces.

The Spherical Valve

The passages through a spherical valve produce little more head loss than the losses in a corresponding length of penstock. Advantage can sometimes be taken of this to effect economies by reducing the size of the valve and using efficient diffuser pipes downstream. In this case, the head loss may be taken as the losses in the diffuser. The cost of the valve can be expected to vary as some function of the diameter, commonly as the square, and a comparison of the value of the head loss in the diffuser with the saving in valve cost will indicate if economies can be effected by a reduction in the size of the valve.

In view of the increasing popularity of the spherical valve some words about the design considerations will be of interest. This valve finds application in high-head service for which its proportions admirably suit

it. The valve body is truly spherical, a shape which results in the lowest stresses due to internal pressure. But it is in the plug where the spherical-valve design finds its greatest advantage. This must be a structure capable of transmitting the loads of the highest penstock pressures to the trunnions without undue stress or objectionable distortion. A little consideration will show the value of the shape selected. A study of the bending moments set up in the plug shows that the maximum stresses occur either at the trunnions or at the downstream and upstream extremes. The simple geometric shapes of the plug permit the maximum section modulus attainable within the confines of a spherical body. Loads applied within either the upstream or downstream seats give, while not identical, at least approximately the same distribution of bending moments, a condition which the symmetrical upper and lower sections of the plug admirably meet. This symmetry also results in the minimum distortion of the seating areas, a factor which contributes in no small measure to the valve's freedom from leakage.

Another important consideration in the choice of this shape is hydraulic in nature. As a valve is closed under flow the dissipation of energy at the valve approaches the value of the generating capacity of the wheel itself. This great energy release can be very destructive if not carefully directed. In the spherical valve energy is dissipated at both the entering and discharge ends and is discharged by the partially closed plug at an angle against the downstream pipe from which it is diffused in two opposing helical actions which dissipate the energy in turbulence.

Controls

No paper on hydro-electric valves would be complete without reference to controls. Here the problem is to reconcile absolute reliability with intermittent operation. This is no easy task. It will demand rugged equipment with thorough engineering, amply powered relays, and above all simplicity. Simplicity cannot be over-emphasised. It is relatively easy to take an initiating signal and amplify the forces to any magnitude needed to perform the desired operation. The problem is greater when the apparatus is used only intermittently with idle periods often extending to months. But when operations are required in carefully selected sequences with appropriate time delays our problems are multiplied. (This is the disadvantage previously ascribed to inflatable seats on butterfly valves. Operation of the discs and the seals must follow prescribed sequences if either the movement of the disc is not to be jammed or the seats are not to be injured). This is also the only disadvantage listed under the spherical valves other than cost. Here the independently controlled seat is basic to the design. These controlled sequences can be further multiplied by the addition of bypass valve operation, venting of the case, etc., with no apparent limit except that of the designer's imagination.

The controls may be either electrical, hydraulic or mechanical. They are usually a combination of two and sometimes all three media. Certain arrangements or practices have shown their superiority. For the conversion of electrical to mechanical power, motors which can be geared down to exert tremendous forces are more reliable than solenoids which may jam in spite of deceptively large safety factors. Glands in hydraulic relays must be carefully selected and designed or they will swell and develop annoying drag after long periods of idleness. Every precaution must be taken to exclude moisture and dirt from electric relays.

All of these problems can be overcome and the increasing use of automatic plants will see, of course, the increase in use of automatic controls for valves. However, we can fairly ask ourselves whether in supervised plants automatics are always superior to hand controls. Automatics can be reliable only with

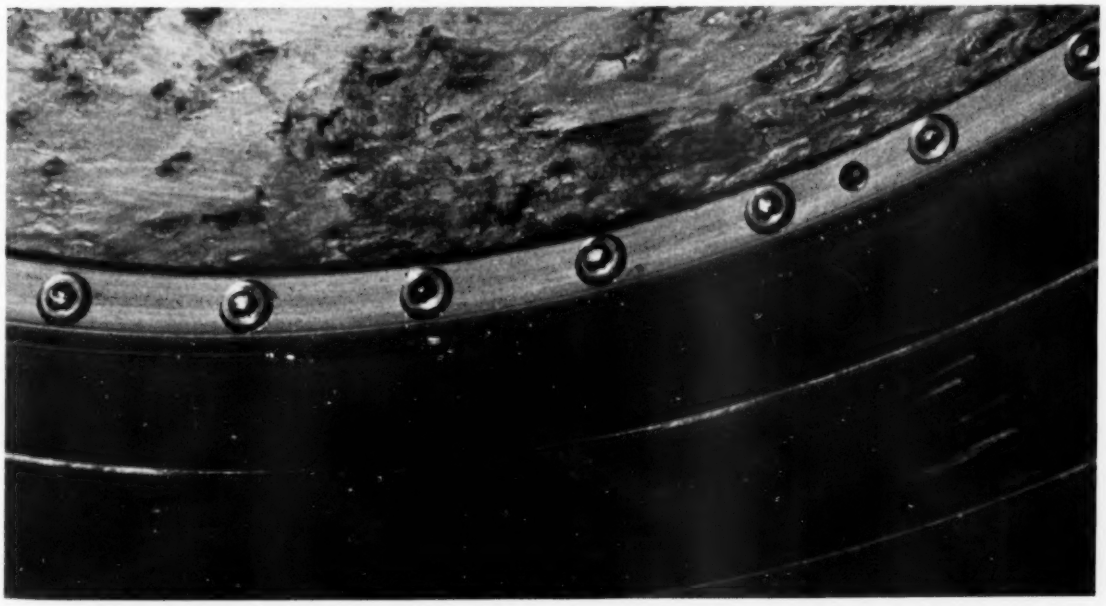


Fig. 4. 51 in. spherical valve under a total load of 2,000 lb. per sq. in. in shop test. The white spots around the seating are drops of water and represent the leakage taking place in half an hour

the careful and methodical inspection such as is regularly scheduled for automatic plants, a service that they do not always receive in supervised plants which are on the line for long periods. Careful consideration will show two advantages to hand controls: First, simplicity with its value for reliability and freedom from maintenance, and second, the protection of equipment which can only come from operation under supervision. Unusual performance or noise will signal to an intelligent operator impending trouble and corrective measures may be taken immediately. Automatics are always blind. They can and, of course, should be designed to "fail safe" but at the best this can only put equipment safely out of service with a loss of load and revenue until supervision can correct the fault. At the worst, improperly applied, it can result in expensive breakdowns. There can be no dry run to check the controls before an emergency shutdown of a penstock or turbine shut-off valve. The disadvantage often ascribed to hand controls that the operator can panic in an emergency is real but can be easily over-emphasised. In any event, an overriding one-shot control remotely operated for emergency shutdown can be added to hand controls which will add very few complications. The author would personally urge that we carefully consider the advantages of hand controls before we climb entirely on the band wagon of automatics.

Fig. 5. 11 ft. spherical valve plug during manufacture

Some Typical Installations

Examples of recent practice in butterfly valves are the three 16 ft. valves supplied in 1957 on the west coast (Fig. 2). Here the valves are installed for shutoff service on 35,000 h.p. Francis turbines operating under a head of 122 ft. Operation is by an oscillating cylinder under an oil pressure of 300 lb. per sq. in. supplied by an independent accumulator tank with self-contained pumping unit. The seats are excellent examples of the hard conical type. Head losses are minimised by a typical converging make-up piece downstream of the body. Expensive make-up joints are eliminated by the use of a riveted joint between the body and the penstock. This permits the correction of incidental misalignment with the penstock, eliminates any stress in "buttoning up" and provides a full-strength joint to anchor the valve to the penstock. It also provides easily accessible dismantling joints if ever the valves must be removed. One of these valves was given a very complete set of field trials including flow shut-down tests over a range in turbine gate settings from speed-no-load to full gate. As was expected, the noise of cavitation during the closing movements was severe, especially in the high-load tests, but there was a gratifying freedom from vibration either in the valve proper or in the downstream piping. The shape of the curve showing torque on the disc was of the typical "S" shape where the cylinder acts to restrain the disc during the early part of the stroke and then exerts the required torque to seat the valve finally (Fig. 6).

For examples of spherical valves we turn to eight valves supplied for turbine shut-off service with impulse wheels of 150,000 h.p. under a head of 2,485 ft. (Fig. 3). These spherical valves are 51 in. in diameter, with water-operated double-seated seals. The valves were designed for a proof pressure of 2,100 lb. per sq. in. with an operating pressure of 1,250 lb. per sq. in. The effectiveness of these seats was demonstrated by shop testing at 2,100 lb. per sq. in. where leakage was held to a few drops over a test period of one half hour (Fig. 4). Controls are fully automatic with optional complete local hand control. The automatics are motor operated with sequences controlled by cam action and electrical interlocks. These valves were given a very complete examination in the shop tests, where many readings of stress and strain were

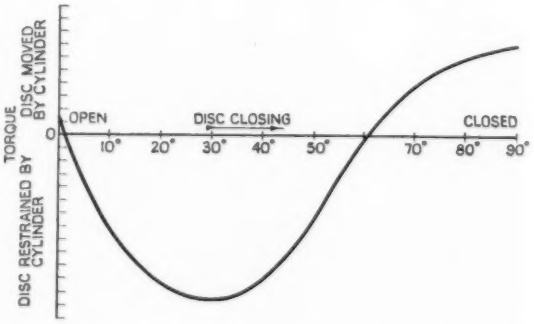


Fig. 6. 16 ft. butterfly valve shut down under flow; turbine gate full open

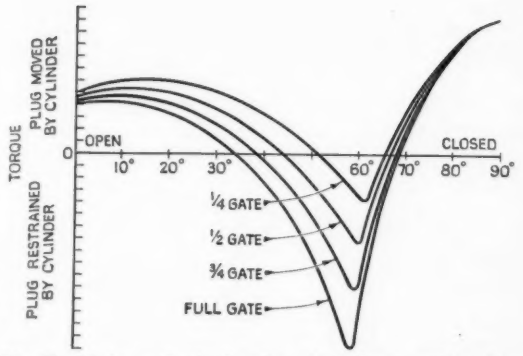


Fig. 7. 51 in. spherical valve shut-down under flow

obtained. Due to a fortunate circumstance, we were permitted to give one of the valves an unusually exhaustive set of trials in the field including shut-down under full flow. The valve performed smoothly throughout the operation without any evidence of vibration either to the valve itself or the immediate downstream structure. The energy dissipated in this operation can best be deduced from the fact that the turbine was developing 160,000 h.p. at the time of the full-flow shut-down. Cavitation under these circumstances was severe. Noise during shut-down was reported at a level beyond description. Again the torque curves were the typical "S" shape, although more sharply peaked than for the butterfly valve (Fig. 7). The performance under the trials again demonstrated the suitability of these valves for emergency closing under severe conditions.

This paper has proved to be a rather rambling discourse on valves. The author has drawn attention to some advantages and limitations of various valves, particularly butterfly and spherical types. Perhaps he has over-emphasised some of the current problems. If, however, by this he has raised some uncertainties regarding the value of these valves he has failed in his purpose; large valves are filling an important and valuable role in hydro-electric service and on the whole are doing it very successfully.

Fig. 8. 11 ft. spherical valve, casting of half the body

Asynchronous and Industrial Sets

Gilbert Gilkes & Gordon Ltd., of Kendal, have recently received an order for a 2,500 kW asynchronous hydro-electric unit for the North of Scotland Hydro-Electric Board's Cuaich Development. The main contractors for the civil, electrical and mechanical work are Balfour, Beatty & Co. Ltd., London. This is the second unit of this size to be supplied to the Board by Gilkes, the other being the Mullardoch installation commissioned in 1955.

This company has given special attention to the development of water turbines driving induction generators and has well over 30 installations of this type in operation. A number of these utilise compensation water in connection with larger hydro-electric and water-supply schemes; they are mostly unattended automatic or semi-automatic installations.

The most recent order for an asynchronous unit of this type has been received from the United Towns Electric Co. Ltd., Newfoundland, for a 1,200 h.p. Francis turbine on a head of 70 ft. This will form the Pitman's Pond section of their New Chelsea scheme.

Other orders received recently include two 440 h.p. Francis turbines for Kasama power station, one of a number of isolated hydro-electric schemes being developed by the Government of Northern Rhodesia. The consultants are Merz & McLellan, Newcastle. Two 435 h.p. recovery turbines have been ordered by The Power Gas Corporation Ltd. for extensions to the Modderfontein ammonia plant of South African Explosives and Chemicals Ltd.

It is not generally realised that a large number of industrial concerns in Britain operate medium and small water power installations. One such firm, The English Sewing Cotton Co. Ltd. has just ordered two 280 h.p. vertical-shaft Gilkes Francis turbines to replace four old machines that have been in operation since 1902 at their Belper Mills in Derbyshire.

From page 382

(b) Entry edges giving increased water passage areas and modified attack angles.

(c) Blade surfaces where roughness can be the seat of cavitation particularly on the blade extrados and sometimes on the runner crown and lower shroud ring.

The direct effect of abrasion, which is an external cause, is badly defined and needs further measurements. Cavitation, on the other hand, is an internal cause depending on flow conditions, local water velocities, waterway shapes and dimensions and absolute suction pressure determined by the runner setting and is, therefore, a design as well as a metallurgical problem.

(To be continued)

Ground Vibrations in Blasting

This article deals with the measurement and character of ground vibrations caused by blasting and makes recommendations by which the intensity of the vibrations can be reduced and damage to structures or property avoided

By *U. LANGEFORS, H. WESTERBERG and B. KIHLSTROM

PART TWO

Character of the Ground Vibrations

The majority of our measurements have been carried out when blasting in hard Swedish rock, with relatively small charges (<100 kg.) and at short distances from the charges. This is undoubtedly the cause of the high frequencies which occur in the measurements. With large rounds and longer distances lower frequencies are obtained. Some typical vibrograms are shown in Figs. 7 and 9. The frequencies recorded lie between 5–500 c.p.s., the amplitudes between 5–500 μ (1 μ=0·001 mm.) with the accelerations below and up to 30*g*.

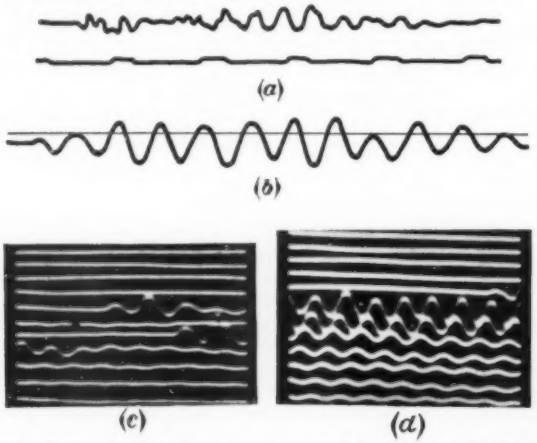


Fig. 9. Typical vibrograms recorded by the Cambridge vibrograph (a *and* b) *and by a cathode ray oscillograph and gauge* (c *and* d) *where the ray has swept from left to right at a velocity of 20 sweeps a second*

In simultaneous measurement of the three components of the ground vibrations it has been found that these are generally of the same order of magnitude, or that the vertical component is predominant. We therefore consider that in many cases it is quite sufficient to register only the vertical component.

Baule[15] has shown that there is a distinct difference in frequency between vibrations which have been measured in the ground and those measured on the ground. Blasting below the surface mostly applied to relatively small quantities of explosives (<50 kg.) and measurements of vibrations at close quarters (<100 m.), whereas surface operators, obviously in the nature of quarry work, are often carried out with up to several tons of explosive and measuring stations are hundreds of metres away. In addition, Baule points out that a harder rock is inclined to give vibrations of a higher frequency than looser rocks.

Damage

A wall the foundations of which are exposed to vibrations is deformed in different ways. Decisive factors are, among others, the relation between the natural frequency of the wall, f_o, and the frequency of the imposed vibrations, f. Damage can be caused by elongation by shearing and bending. The connection between these magnitudes and particulars of the ground vibrations are first determined, having regard to the elastic properties which characterise the wall (Fig. 10). Parallel with this estimate, however, allowance must be made for the fact that local irregularities and a static state of tension which may exist, can lower the damage limit and thereby finally decide the conditions when there is a border case between damage or not.

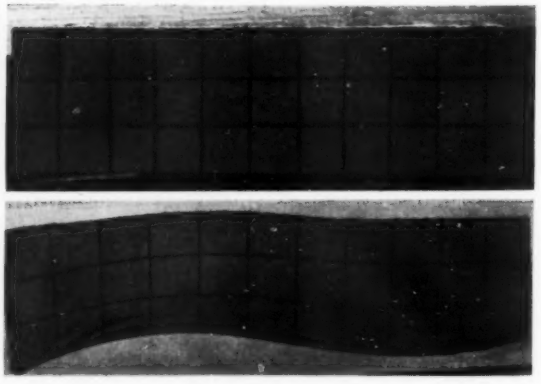


Fig. 10. A wave expanding in the ground gives compression, shearing and bending stresses in the wall

The subsequent discussion may be summarised by saying that the variables which can decide the damaging action are all of the type

$$S\,(\alpha,\beta,\gamma) = \text{constant}\ A f^{\alpha} c^{-\beta} f_o^{-\gamma} \quad \ldots\ (10)$$

in which A is the component in a horizontal or vertical line (A and A_1 respectively) of the observed ground wave, f the frequency belonging to the amplitude, c a factor which depends on the length along

* Nitroglycerin A.B. and Swedish Detonation Research Foundation, Stockholm.

which the deformation is distributed, e.g., so that c indicates the propagation velocity for the ground wave when $c=\lambda f$. When applying the expression to wave propagation in the wall the symbol u is used instead of c. The term f_o indicates the natural frequency of the wall for forced vibrations of the type which is analysed with the aid of (10). When f_o does not enter as a factor then $\gamma=0$ and $S(\alpha, \beta, 0)$ is indicated as

$$S(\alpha, \beta) = \text{constant } Af^{\alpha}c^{-\beta} \qquad \ldots (10')$$

The object is consequently first to determine which values of β and α apply under different conditions, i.e. to demonstrate the connections which apply qualitatively. For practical application it is then required to determine by experiment the magnitude of S, which corresponds to a definite risk of damage.

Hitherto, in view of the difficulty in determining the propagation velocity c and u in each individual case, the same value has hitherto been used, i.e. $c=2{,}500$ m/s, but the errors which arise in doing this are too great to be acceptable, as other factors are known with considerably greater accuracy in the present state of affairs. In the absence of wave-velocity determinations we must, however, refrain for the time being from a further experimental discussion of the influence of c. In examining the practical results obtained a comparison can often only be made for the time being between the influence of A and f. If f_o is not included the indication

$$S(\alpha) = \text{constant } Af^{\alpha} \qquad \ldots (10'')$$

Compression-elongation. For a vertical vibration the frequency of which is slow in relation to the natural vibration of the wall, $f/f_o<1$, the wall moves with a constant acceleration along its entire height. For acceleration in a downward direction with the maximum value a the maximum elongation in the wall is

$$\epsilon=\rho Ha/E \qquad \ldots (11)$$

in which ρ is the density of the wall, E its modulus of elasticity, H its height and $a=2\pi f=4\pi^2f^2A$. Furthermore u is $=\sqrt{E/\rho}$ and $f_o=u/(4H)$. Insertion gives

$$\epsilon=\pi fv/(2f_ou)=\pi^2f^2A/(f_ou) \qquad \ldots (12)$$

In this case are $\alpha=2$, $\beta=1$ and $\gamma=1$.

When the frequencies of the incoming vibration are much larger than the natural frequencies of the wall, $f/f_o>1$, entirely different conditions apply. The ground then has time to make one or more full vibrations before the compression wave reaches the upper surface of the wall. When the ground moves vertically in the direction dy in the time dt, the former is distributed as an elongation or compression along $u.dt$ of the wall, in which u indicates the wave velocity in the wall. The relative elongation will be

$$\epsilon=dy/udt=v/u=2\pi fA/u. \qquad \ldots 13)$$

This corresponds to a damage magnitude of the type $S(1, 1)$ with $\alpha=1$, $\beta=1$ and $\gamma=0$.

For the relative elongation the damage factor S therefore changes character with the ratio f/f_o. The relation is perhaps best made clear by a representation according to Fig. 11, in which ϵ is regarded as a function of f/f_o at a given vibration velocity, e.g. $v=100$ mm. per sec. For high values ϵ is constant. In the region $f/f_o=1$ a resonance peak is obtained which, due to the damping conditions in the wall, can give elongation values noticeably above the lines indicated in Fig. 11. These hold good for $v=50$, 100 and 200 mm. per sec. if $u=2{,}500$ m. per sec.

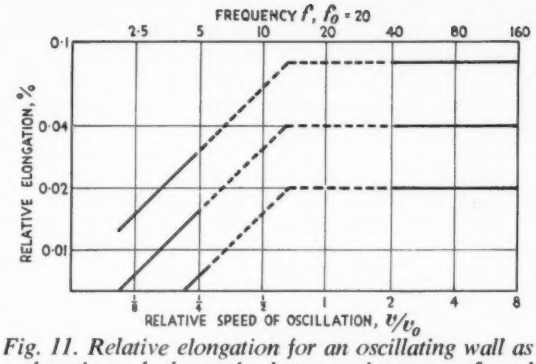


Fig. 11. Relative elongation for an oscillating wall as a function of the ratio between frequency f *and natural frequency* f_o *at varying vibration velocities*

When, in order to judge conditions, data are required of the natural frequency of the wall, a diagram for calculating this as a function of the wall height H and the propagation velocity u is made as in Fig. 12. The horizontal component of the ground vibrations also gives the compression-elongation in the wall. For a wave which spreads in the longitudinal direction of the wall with the velocity c, the same discussion applies as for a compression wave which spreads upwards along the wall. A factor $S(1, 1)$ is also obtained here.

$$\epsilon_1=v/c=2\pi fA/c. \qquad \ldots (14)$$

Shearing. A surface wave which spreads with a velocity c along the ground induces vertical vibra-

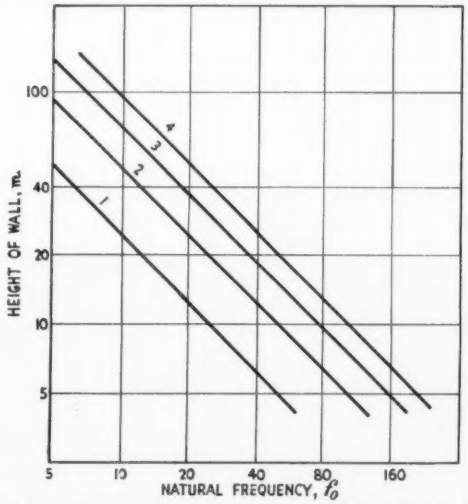


Fig. 12. Natural frequency as a function of height of wall and velocity of sound u *in the wall. The curves are for:* u = *1,000, 2,000, 3,000, 4,000 m/s*

tions, which, in addition to acceleration effects, cause shearing stresses which are geometrically characterised by angular alterations in minor parts. It is evident from Fig. 10 that such an effect depends on frequency, amplitude and wave velocity, so that the shearing increases in proportion to A and f and, inversely, to c. For the shearing angle

$$\gamma=dy/dr=v/c=2\pi fA_1/c \qquad \ldots (14')$$

applies with signs according to Fig. 10, i.e. the same analytical expressions as in preceding cases accord-

ing to eq. 13 and 14. It should be pointed out, however, that maximum shearing can be obtained by the slow surface wave while the elongation maximum arises through another part of the wave system, e.g. the more rapid compression wave. Entirely different values then apply of course to f, A and c in (14) and (14′).

Bending. Apart from the effects mentioned, the vertical vibrations cause the wall to bend and this gives rise to elongation and compression in the upper part. The maximum value is indicated by

$$\delta = H\, d^2y/dr^2 = Ha/c^2 \qquad \ldots (15)$$

The horizontal vibrations parallel to, as well as perpendicular to, the wall also give bending vibrations. Without entering into these in detail it can be mentioned that they are of the type S (2, 2) as in eq. (15).

Local effects. The types of deformations discussed here can of course be increased by superposition of stationary local tensions already existing in the wall. This implies that the limit for damage is reduced by a certain amount, but the above-mentioned expression for S can be expected to stand in the sense that, for an actual case, a release of cracks is obtained if γ reaches a given value whether this is attained by high A or f values. The limiting value depends finally on the actual state of the building. Here we must allow for the fact that cracks are normally developed without being influenced by ground vibrations. When a building approaches the limit for such a release even insignificant vibrations can cause cracks.

In taking measurements it is often found that there are considerable variations in the intensity of vibrations in one and the same building even if the measuring is carried out in the foundations. The reason is that the foundations are not in contact with a uniform body of rock, that only part of the foundations stand on rock, or that holes and fissures in the rock shut off the effect of the vibrations in certain sections. In such cases differences in amplitude or phases can be obtained within a limited section of the building and local deformations may occur which considerably exceed those calculated solely from the wave magnitudes. Such a case has given rise to the pronounced shearing shown in Fig. 13. Fig. 13*b* shows a case in which existing tensions in a wall have been released by the production of cracks.

A further type due to local effects is illustrated by Fig. 13*c*; here the cause of the cracking is to be sought in a locally restricted amplitude or phase difference along a line in the building. Such differences can also arise in a homogeneous foundation when the prerequisites for the wave propagation in two adjoining sectors differ. Another example of this type is the cracking which often occurs close to a chimney, in the joints close to stoves and where different materials meet.

Vibration energy. It has often been indicated in literature of recent years that the vibration energy

$$E_{sv} = \frac{1}{2}\rho v^2 \qquad \ldots (16)$$

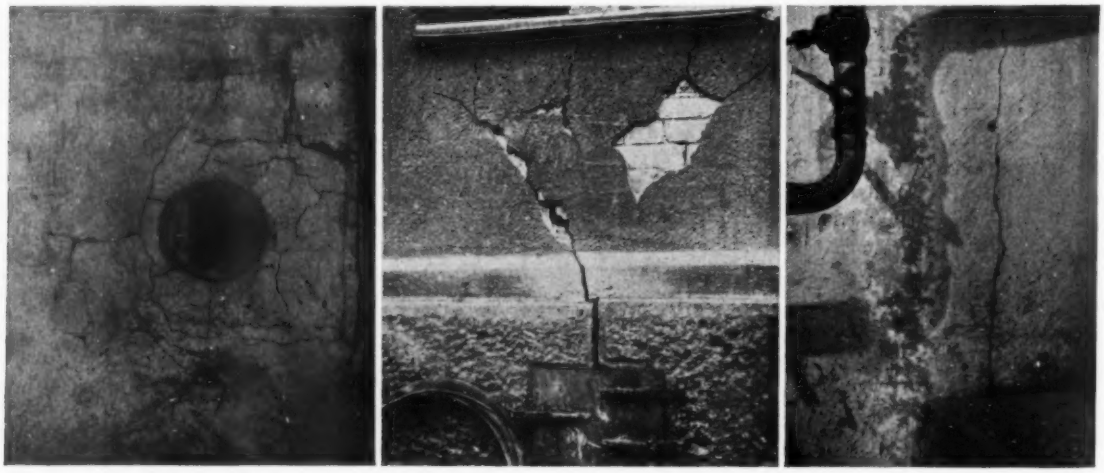
is the determining factor in the damaging effect. This cannot, however, generally be the case. For a vibration with a sufficiently low frequency, the velocity of motion, and consequently the energy, can be high at the same time that the acceleration can be made as small as one chooses. There is then, just as in the stationary case with a constant velocity of translation, no reason for damage to be caused. The vibration energy cannot be transmitted into any other form of energy.

If damage is to be discussed with energy as the starting point it seems more reasonable to consider the quantity of energy that is supplied and removed per unit of time. We then get a quantity

$$W = \rho v^2 f = \text{constant}\ A^2 f^3 \qquad \ldots (17)$$

of the type S (3/2). W is of the same character as the magnitude $\frac{1}{\pi} va$ as defined by Zeller and for which the unit vibrar (m^2/s^3) has been suggested. Proof that W might be related to any type of damage has not, however, been submitted.

Subjective estimate. In blasting, consideration should also be paid to how the ground vibrations are



(a) *(b)* *(c)*

Fig. 13. Cracks caused or released by ground vibrations from blasting. (a) *Cracks round a fixing bolt;* (b) *shear cracks near the foundation of a plastered brick house:* (c) *cracks close to a bearing wall*

subjectively conceived. A great deal of the irritation which arises between the blaster and his environment is due to the fact that a layman is very apt to acquire a wrong conception of the risk of damage. Another aspect is that the blasting is regarded in itself as something disagreeable.

Reiher and Meister have investigated human reaction to vibrations. Their results are reproduced in Fig. 14. The lines indicate when the effect has been considered to be (a) scarcely noticeable, (b) clearly noticeable, (c) irritating and (d) disagreeable. These

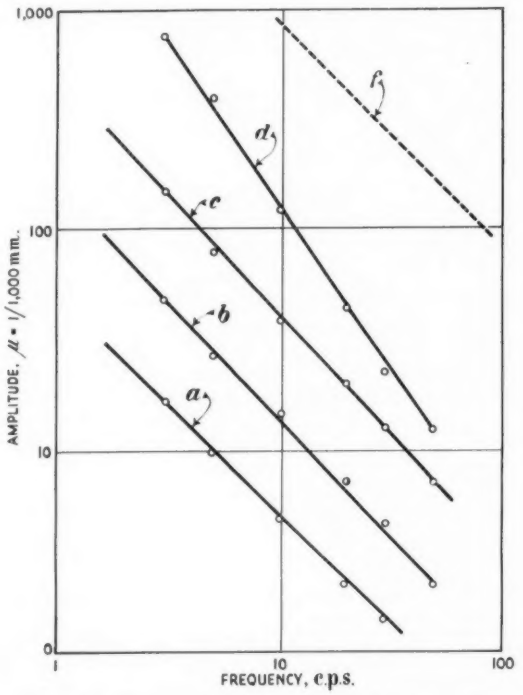


Fig. 14. Interpretations of ground vibrations

facts are valuable especially in connection with complaints which show that those concerned considered the vibration to be injurious. The diagram shows that a man normally reacts strongly long before there is reason to apprehend damage to his house. In point of fact a very large number of complaints which have been made have proved to be unwarranted.

When we consider the other aspect of the problem, the discomfort, we may well ask whether an unexpected and powerful blast is immediately associated with damage and destruction. If people are told that suspicion is aroused long before any damage can possibly be expected this should elucidate matters and reduce the subjective reaction. But even so there may still be discomfort, which should be avoided as much as possible. The number of blasts can often be reduced, due warning of them given and, above all, blasting at night should be avoided. In comparison with other causes of discomfort in a modern city, we may well ask whether a blast carried out in a reasonable manner at a reasonable time may not be regarded by a normal human being as a healthy and distinct tone in a blurred hubbub!

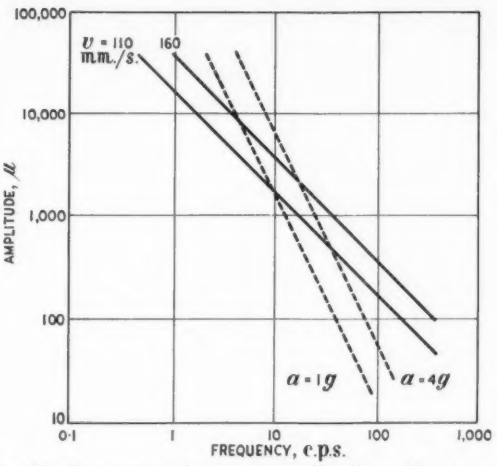


Fig. 15. Connection between amplitude and frequency

Discussion. The alternatives which will be discussed are according to (11) and (17)

$$S(\alpha, \beta) = \text{constant } A f^{\alpha} c^{-\beta} \qquad \ldots (10')$$

with $\alpha = 1, 3/2$ and 2.

It has previously been shown[5] that at low frequencies ($f \leq 10$ c.p.s.) there is a risk of damage due to S (1, 1), and that the acceleration with S (2, 0) or W with S (3/2, 0) does not attain a sufficiently high amount for damage until this has already been caused by S (1, 1).

The connection between amplitude and frequency for some current values of v and a is indicated in Fig. 15. It will be seen from the diagram how the relation between the quantity v proportional to S (1, 1) and a proportional to S (2, 0) changes according to frequency, and demonstrates why S (1, 1) dominates at low frequencies. The inverse conclusion that the acceleration S (2, 0) is decisive at high frequencies is, however, not correct. This is due to the fact that when S (2, 0) has been obtained in estimating the damage a prerequisite has been low frequencies $f < f_o$. For high f values other conditions, which lead to S (1, 1) apply. There remains uncertainty only in the vicinity of $f \simeq f_o$.

In order to judge which factors in practical experience are decisive, we have compiled our measuring values in Fig. 16, in which the frequencies and amplitudes obtained have been indicated, in conjunction with results from a subsequent examination. The investigation has covered a frequency range of 50–500 c.p.s. It is evident from the table that in (10′) $\alpha = 1$ gives satisfactory agreement with the experimental matter. This, on the other hand, is not the case either for $\alpha = 2$, or $\alpha = 3/2$.

In addition to showing the experimental connection between A and f, the diagram also gives a graduation of the risk of damage in relation to quantitative data on $v = 2\pi f A$. This is summarised in Table 1.

TABLE I.—RISK OF DAMAGE IN NORMAL HOUSES ON ROCK (c = abt. 3.000 m/s)

v	v/c	Results in normal house building
70 mm./s.	23	No noticeable cracks
110 mm./s.	37	Fine cracks and fall of plaster
160 mm./s.	53	Cracks
230 mm./s.	76	Serious cracks

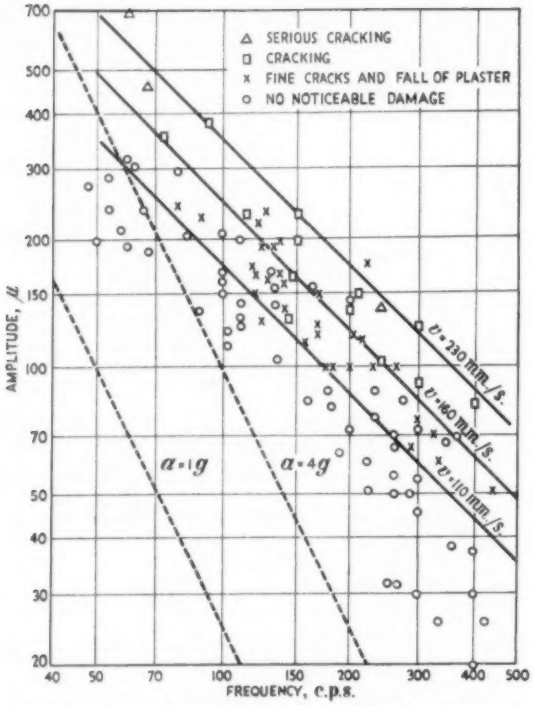


Fig. 16. Connection between amplitude, frequency and damage

In the examples shown in Figs. 13 *a*, *b* and *c* the vibration velocity has in all cases been greater than 160 mm. per sec.

Reduction of Ground Vibrations

The ground vibrations which are caused by a single charge acquire a maximum amplitude A only after one or several previous minor deflections. The vibration is most often of a relatively short duration, and in most cases only three full vibrations can be expected to have an amplitude greater than $A/2$; all the others can more or less be ignored. This means that at intervals greater than 3 T, ($T=1/f$ time for a full period) it can be reckoned that there is no collaboration between two different shots.

If the interval is shorter, conditions are more complicated, as there will be co-operation between the different wave systems. How the different factors of time delay, number of holes, and frequency affect the final result has been made clear by Langefors,[5] and Johansson and Langefors.[9] An interference effect is obtained which implies that, when the delay time τ is as great as the vibration time T, or an integral multiple hereof, co-operation is obtained between the different delays so that the vibration effect adds up. This applies when H is an integer in the ratio

$$\tau = HT \qquad \ldots (18)$$

On the other hand, when H is an odd number of semi-values the different wave systems extinguish or weaken one another. This takes place almost completely when $H=\frac{1}{2}$; but for higher values of H than 5/2 the effect, either as regards extinction or reinforcement, does not play a major role.

An arranged interference can also, however, in rounds of several shots, be obtained in another way.

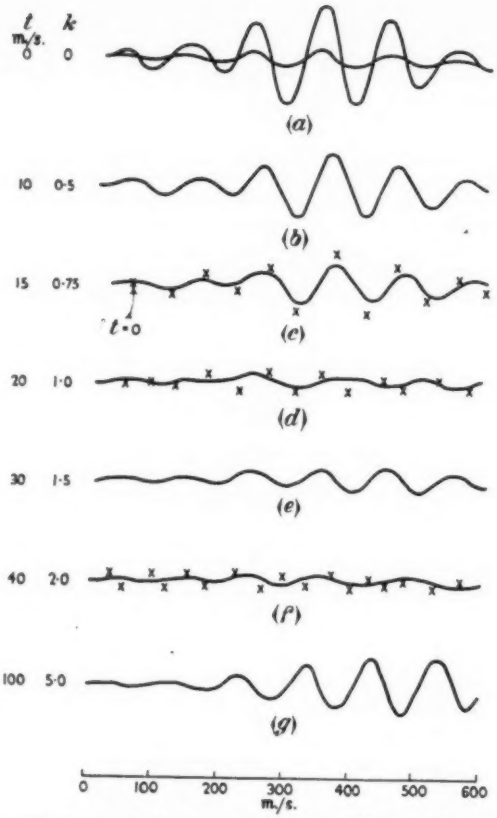


Fig. 17. Ground vibrations from five different charges

The general condition is that k shall be an integer, but not the ratio between k and n, i.e. $k/n \neq 1, 2, 3, \ldots$

$$n\tau = kT \qquad \ldots (19)$$

in which n indicates the number of intervals. The implication of this is that the spread of the round in time ($n\tau$) shall be distributed over one or a number of full periods of the vibration concerned. This is an important extension. According to the previous simple interference conditions a certain interval is required for every frequency; the interference condition according to (19) can, however, be fulfilled within very wide limits.

It has been shown on many occasions in literature that an increase in the size of the round by an increased number of intervals gives the surprising result of a decrease in the amplitude of the ground vibrations. This is clearly a consequence of the above condition if, by increasing the number of intervals, a k value is obtained which approaches an integer.

With interval times which are small in relation to the natural vibration time, the number of intervals is chosen large enough to ensure that n amounts to the time of at least one full period. If it is not possible to adapt the interval times exactly so that k becomes an integer, then it can be calculated that as large a part of the entire round as corresponds to the nearest integral value fulfils the interference condition and that the excess (or missing) part makes a contribution which co-operates in practice.

Example. Ground vibration with $f=10$ c.p.s., $T=100$ millisec, $\tau=30$ millisec, $n=5$. The amplitude from a

single hole is $A = 20\ \mu$. This implies that the round in instantaneous ignition can give an amplitude $A = 100\ \mu$. For the short-delay round discussed, $n\tau = 150$ millisec and $k = 1{\cdot}5$. The spread of the round in time is 1/3 too long if we count to $k = 1$, and just as much too short if we count to $k = 2$. Two-thirds of the round fulfils the interference condition and is eliminated, the remainder co-operates. An amplitude of approximately 30 μ may be expected, i.e. as from 1·5 shots in simultaneous ignition (see Figs. 17 *a* and *e*).

With time intervals which are large in relation to the time of natural vibration, we approach the state in which the vibration from each shot has largely died away before the one succeeding manifests its maximum amplitude.

When the interval time is just as large or almost as large as the vibration time, or double the value, $\tau \simeq T$ or $2\ T$, it is impossible to avoid the co-operation of the vibrations from different charges. On the other hand, if the rounds in question have a large number of intervals, the shots that lie at a relative time distance of $3\ T$, or more, can generally be expected to be non-co-operative. For that portion of the round which comprises intervals Nos. 0, 3, 6, 9, etc. (or 0, 2, 4, 6, etc. when $\tau = 2\ T$), the maximum amplitude will be of the same order of magnitude as for a single shot. The resulting vibration is then made up from three (or two) such portions of the round. The whole round thus gives an effect which corresponds to 3 (or 2) co-operating shots. If this reduction of the vibration is not sufficient, all that remains to be done is to leave out one or two intermediate intervals.

These viewpoints can be applied at major stationary blasting places, such as mines and quarries where blasting under similar conditions is carried out for a lengthy period. The character of the vibrations can then be determined, and a suitable interval time and number of intervals calculated.

In practice it is important that the interference condition should also permit *unarranged interference* to be used. This is obtained if the time spread for a number of charges is large enough to cover at least a full period of the vibrations even if this spread is distributed quite arbitrarily. The probability that every one of a large number of shots will happen to be in exactly the same phase can then be practically ignored. A ground vibration will be obtained which is reduced to half, or less, according as the spread increases to higher values than the vibration time. In order to calculate the effect of the unarranged interference, the reduction factor r at different frequency values, the natural vibration period and the values of the scattering ($\pm\Delta\tau$) are indicated in Table II.

TABLE II. REDUCTION FACTOR (r) FOR THE TOTAL CHARGE (Q_t) WITHIN ONE AND THE SAME INTERVAL IN UNARRANGED INTERFERENCE. THE VIBRATION EFFECT IS ASSUMED NOT TO BE LOWER THAN THE VALUE WHICH IS OBTAINED WITH A SINGLE HOLE.

f c.p.s.	T ms	r				
$\Delta\tau =$	± 5	± 10	± 25	± 100	± 200 ms.
5	200	1	1	1	1/2	1/3
10	100	1	1	1	1/3	1/3
20	50	1	1	1/2	1/3	1/3
50	20	1	1/2	1/3	1/3	1/6
100	10	1/2	1/3	1/3	1/6	1/6
200	5	1/3	1/3	1/3	1/6	1/12
400	2.5	1/3	1/3	1/6	1/12	1/12

The table applies to a number of shots which are ignited with the same number of intervals with scattering $\pm\Delta\tau$, e.g. defined so that 5/6 of all values of the scattering lie in an interval which is $2\ \Delta\tau$ millisec. If a short-delay detonator is used with enclosed delay the scattering for the two lowest numbers is $\pm$ 5 millisec., for the three succeeding numbers $\pm$ 10 millisec. up to about interval 10, and still greater for higher intervals. For second-interval detonators the scattering is $\pm$ 100 millisec. or more.

Example: In a single bench row six charges are initiated, all of them with short-delay blasting caps No. 5. The blasting is carried out in Stockholm granite and the frequencies which may occur are at least 100 c.p.s. According to Table II the reduction factor r is then $= 1/3$. A vibration which corresponds to two of the charges ignited instantaneously is obtained. On the other hand, if the ground vibrations have a frequency of 20 c.p.s. no essential reduction of the vibration effect compared with instantaneous ignition can be expected.

For different interval numbers it can be reckoned that co-operation does not occur when $\tau \geqq 3\ T$. With $\tau = 30$ millisec., which has often been used hitherto, the maximum charge permitted can be used in every single interval after correction with the reduction factor, as long as the frequency is $f \geqq 100\ p/s$. This usually applies in blasting in Swedish bedrock.

In softer kinds of rock or other materials, the frequencies are often between 20 and 50 c.p.s. For 20 c.p.s., $T = 50$ millisec., a reduction cannot be counted on between different charges in the same interval, as the distribution will normally be included in a semi-period. In those cases in which it is desired to use the maximum charge per hole only one such charge can be used in every interval. In this case the interval time is 30 millisec. $\sim T/2$ and the vibrations from the consecutive shots may be expected to be almost entirely extinguished.

For 50 c.p.s. T is $= 20$ and the reduction factor is $r = 1/2$ if $\Delta\tau = \pm$ 10 millisec. The effect of a number of charges in the same interval is halved. In this case close co-operation is, however, obtained between two or three consecutive intervals if $\tau = 30$ millisec. If the number of intervals is increased to 4 or 5 these will counteract to some extent the earlier ones and the total vibration corresponds to approximately two co-operating intervals.

If the interval time does not closely approximate to the vibration time an increase in the number of intervals means that here, also, an unarranged interference is obtained to some extent because there is then very little likelihood of getting exact co-operation for several intervals in succession. This generally plays a minor role, however, because of the short duration of the vibrations. The spread in time is of greater importance here, in addition to which a considerable improvement can be obtained by choosing the number of intervals or interval times by an arranged interference.

(To be continued)

Power Penstocks. In the concluding portion of this article in our August issue we regret that certain figure references in the text were incorrect. On page 307, line 6, Fig. 14 should read Fig. 15; on page 308, line 1, Fig. 15 should read Fig. 17, and in the second column on this page, Figs. 16, 17 and 15 should read Figs. 20, 21 and 17.

Hydraulics Research Board Report

THE Hydraulics Research Station at Wallingford, Berkshire, opened in 1947 and the annual report for 1957 which has just been published* gives an interesting account of the great progress that has been made during the first decade of its existence. During 1957, more projects were under investigation than ever before and the facilities at Wallingford were extended to accommodate a large number of models, including three which are directly concerned with hydro-electric development.

Two of these studies, undertaken for the consultants to the Malaya Electricity Board, and relating to the Cameron Highlands hydro-electric scheme (see WATER POWER, April 1958, p. 123), were intended to establish final designs for a stilling basin at Ringlet Falls on the Sungei Bertam river and a weir on a smaller river known as the Sungei Telom. The Sungei Bertam flows in a narrow granite gorge and, for reasons of economy, the stilling basin would have to be as small as possible and of simple construction. A design was evolved, in which an overshot tilting gate intended to carry normal flows and floods up to 2,500 cusecs is placed on the dam crest and a system of undershot radial gates is provided to pass higher floods up to an assumed catastrophic value of 32,000 cusecs.

A model to a scale of 1/30 was constructed in which the full flood discharge was represented by a little more than 6 cusecs. An overshot tilting gate with a small opening for low flows was provided to regulate the tailwater levels.

After a number of trials, two changes were made in the design. A fillet plane was fitted across the spillway face to prevent the flow from the first gate in the system falling into the basin as a free jet, a fault caused by the inclination of the guide wall across the basin floor. In addition, a 10 ft. high scoop was placed at the foot of the basin wall under the second gate because in the original design it was found that, with all gates open, any standing wave formed in the basin was swept away at flows exceeding 20,000 cusecs. The scoop intercepted part of the flow and reflected it across the basin to interact with the flow down the other side, thus forming a buffer but not a standing wave. Experiments were made with stilling basins large enough to allow the formation of a true standing wave and the most satisfactory shape was similar to that in the original design but was 117 ft. wide.

The second model investigation for the Cameron Highlands hydro-electric development concerns the ultimate design for a weir to divert the flow of the Sungei Telom river into a tunnel leading to the Ringlet Falls reservoir. The flow, which is to be augmented by water from a tributary, the Sungei Kial, will pass via a settling area to a drop shaft and tunnel. Recent flow data show an average of 18 floods per annum which would result in heavy discharges over the main weir but the flow from the Kial will only be 35 cusecs at normal discharge, with a maximum of 220 cusecs.

The third study of hydro-electric interest concerns the excavations required to increase the discharge at Ripon Falls, Uganda, some 3,000 yards upstream from Owen Falls (see WATER POWER, June 1954, p. 206). When the Owen Falls power station is operating under full load, it requires a maximum flow of 33,600 cusecs but the maximum discharge corresponding to any particular level in Lake Victoria is determined by weir action at Ripon Falls and a head loss of only 2 ft. is available between the lake and the head pond. At Ripon Falls the river is about 900 ft. wide and the flow is divided into a number of separate channels making it impracticable to seek a solution by analytical methods.

A geometrically similar model was constructed to a linear scale of 1/100. The model included a reach extending from about 1,500 ft. upstream to 400 ft. downstream from Ripon Falls. After preliminary study, a series of tests was made with material excavated from the west side of the Falls and it was found that the upstream shallow reach would take over control of the flow at an early stage in the clearance of the Falls. Tests were then undertaken to determine to what extent, and where, material should be excavated to allow a discharge of 33,600 cusecs at specified levels. In the final solution, two channels have been cut through the upstream shallows and, in order to produce better alignment of flow, the cut at Ripon Falls was made on the east side instead of the west, the rock being dumped immediately upstream and downstream of the Falls. Approximately 48,000 cu. yards of material will be excavated from the upstream shallow reach and 8,600 cu. yards from Ripon Falls.

During 1957, the Hydraulics Research Station devoted about 80% of its time to specific problems, the remaining 20% being used for background research. The wide range of studies undertaken for local authorities, government departments, consulting engineers and contracting companies well demonstrates the part that the Station plays in providing engineers with sound basic designs and solutions to problems arising in open-channel hydraulics.

A.C. Network Analyser. Associated Electrical Industries Limited have published an 18-page booklet to explain the use of this analyser which has now been in constant use since 1947. A wealth of experience has been accumulated of many different power and transmission systems all over the world. Any supply authority, manufacturing company, or scientific body wishing to make use of the analyser is recommended to refer to The Engineer in Charge, A.E.I. Network Analysis Department, 20 Neasden Lane, Willesden, London, N.W.10.

The Federation of British Industries have published a list of "Selected British Technical Journals" which is intended primarily for the use of former F.B.I. overseas scholars and other overseas engineers trained in Britain; it is on general sale at the F.B.I. headquarters at 21 Tothill Street, London, S.W.1, price 2s.

* "Hydraulics Research, 1957." Department of Scientific and Industrial Research. Published by H.M.S.O. Price 5s. 6d.

Book Reviews

Water Power Engineering. By Rolt Hammond, A.C.G.I., A.M.I.C.E. Published by Heywood & Co. Ltd., Ingersoll House, 9 Kingsway, London, W.C.2. 302 pp., 73 ff. Price 50s.

The insatiable world-wide demand for more energy has given added impetus to the exploitation of all sources of power. This book provides an excellent introduction to the whole field of water power engineering and it will be of great interest to both engineers and students. Mr. Hammond has covered all the main aspects of this subject and, while he has made brief incursions into the past, he also gives an interesting account of current development with particular reference to projects for the harnessing of tidal energy.

Multiple Purpose River Development. Studies in Applied Economic Analysis by J. V. Krutilla and O. Eckstein. Published by The John Hopkins Press, Baltimore 18, Md., 301 pp., 17 ff., 1958. Distributed in the United Kingdom by Oxford University Press, Amen House, Warwick Square, E.C.4. Price 36s. net.

This is an important book dealing in great detail with all economical aspects of river development. Economic analysis forms an essential part of any hydro-electric scheme, particularly in this age of heavy capital investment. The authors present the analytical framework used to define the conditions required for economic efficiency and they conclude that exclusive reliance on the market mechanism to obtain efficiency would involve an excessive concentration of economic power.

There has always been violent controversy about the effectiveness and accuracy of objective analysis in water development problems but the authors of this work are firmly convinced that a large measure of such analysis is possible. Although they are primarily concerned with specific problems of evaluating alternative methods of approach to multi-purpose river development in the United States, their study first considers a set of fundamental concepts of a general nature, including the concept of economic efficiency and the consequences of income redistribution.

The third chapter discusses market mechanics as regards water resources, flood control, irrigation, inland water navigation and hydro-electric power. In hydro-electric projects, transmission losses restrict the area in which power can be marketed economically and thus the inability to expand capacity by increments, which are relatively small in relation to the market potential, will probably depress rates at which the total energy available can be marketed. A short-term power surplus will normally be disposed of by bargaining, in which case bilateral monopoly is the more appropriate theoretical model for the setting of rates and disposition of output. Long-term contracts at dump-power prices may have to be negotiated in order to dispose of a short- or medium-term surplus. While this may be of great advantage to the bargain-hunting buyer, it is but cold comfort to the investor in hydro-electric development.

Comparatively few problems arise in estimating costs for a given development project. Markets exist for services needed in building projects and consequently market rates of hire for services, and established prices for construction materials, are generally available although the law of supply and demand might affect the rates of hire for local labour.

Estimating the social cost of capital services for a given project presents a different kind of problem. Since only part of the services provided by multiple-power river projects are marketable, capital for the project is not obtained by competitive bidding in the market.

Although this book primarily concerns economic problems arising in the United States, where private enterprise often confronts State investment, the conclusions have equal interest to anyone engaged in similar analyses in any geographical location. The study is particularly helpful in evaluating the advantages and disadvantages of partnership between the State and private interests in hydro-electric development.

Famous Cableways of the World, by F. E. Dean. Published by Frederick Muller Ltd., Ludgate House, 110 Fleet Street, London, E.C.4. 144 pp., 47 ff. Price 9s. 6d. net.

Engineering affects the life of every mortal but some of the spectacular technical achievements intrigue and excite the layman more than others. This entertaining book traces the history of that fascinating form of transport known as the cableway and shows how cable and rope have been put to many uses ranging from the antediluvian telpher to the rocket-fired nylon rope that has saved countless lives in shipwrecks.

The author has shown how cableways are used during the construction of dams and power stations and the illustrations emphasise the enormous part they play in civil engineering work on any hydro-electric project.

In the final chapter, Mr. Dean has explained how wire ropes are made and, for the uninitiated, this provides an absorbing conclusion to an interesting, excellently written and lavishly illustrated book.

Introduction a L'Analyse Dimensionnelle et aux Problèmes de Similitude en Mécanique des Fluides. By R. Comolet. Published by Masson et Cie, 120, boulevard Saint Germain, Paris. 116 pp., 18 ff., Price 1,600 francs.

This excellent book is divided into two sections, the first dealing with dimensional analysis while the second is devoted to hydraulic similitude. Many previous works have made frequent but brief references to dimensional analysis but this is almost the first time that an author has produced a detailed study of calculations by this method. Dimensional analysis can be applied to almost all branches of physics and it is of particular value when problems having many variables are encountered. All major hydraulic or aerodynamic projects are now preceded by tests and measurements on scale models and M. Comolet mentions that although tests on a model of the Donzère Mondragon power station on the Rhône cost 60 million francs, they enabled work to be completed one year earlier than would otherwise have been possible.

The second section discusses the principle and

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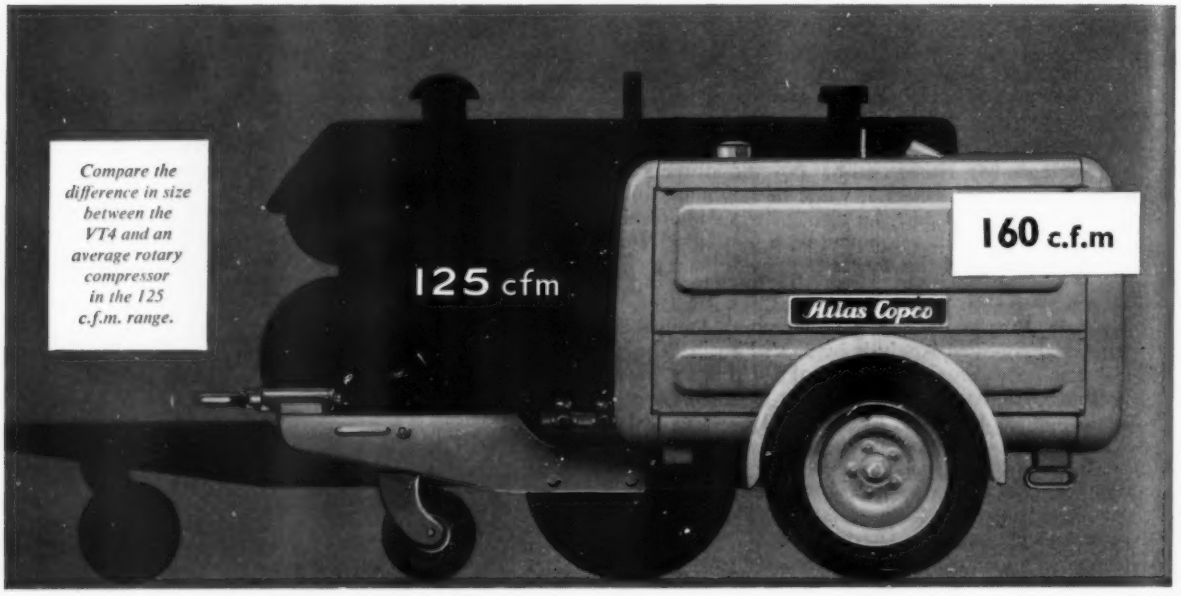
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125 cfm
160 c.f.m
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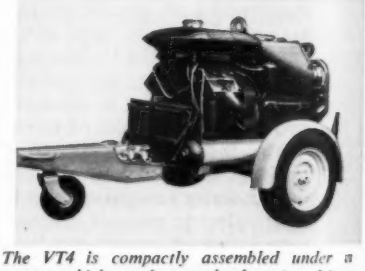

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P.38

theory of hydraulic similitude with particular reference to scale model tests. A model is, of course, generally geometrically similar to the prototype but, especially in the cases of ports and rivers, the vertical and horizontal scales are not the same and the model is therefore distorted. In the final chapter M. Comolet has compared the theories of dimensional analysis and similitude.

This book (in French) is excellently written and well presented. It will be of great interest and help to all engineers concerned with the study of models and the interpretation of measurements obtained from them.

International Electrotechnical Vocabulary. I.E.C. Publication 50(35). International Electrotechnical Commission, 1 rue de Varembé, Geneva, Switzerland. Price Sw.F. 1·50.

I.E.C. Publication 50(35), which has just been issued, is the Electromechanical section of the Second Edition of the International Electrotechnical Vocabulary, which will contain 24 groups when complete. It comprises some 90 terms and definitions in French and English, together with the equivalent terms in German, Spanish, Italian, Dutch, Polish and Swedish. Indices are provided for each of the eight languages used.

The terms and definitions are divided into the following sections: General terms; machines and apparatus for lifting, handling or conveying; miscellaneous applications; domestic applications; automobile applications; agricultural applications; applications to clocks; signalling devices.

The Upper Holston Projects. Report No. 14. Published by the Tennessee Valley Authority, Treasurer's Office, Knoxville, Tennessee. 1,236 pp., 408 ff. Price $4·50.

This report details the planning, design, construction, initial operations and costs of four major dams and reservoirs in the eastern tip of Tennessee. Watauga and South Holston dams are earth-rockfill structures, while Boone and Fort Patrick Henry dams are of the concrete gravity type. The report includes as an appendix the improvement of the minor Wilbur project in the same area.

In addition to the importance of these hydro-electric projects for local flood protection and in the overall system operations, the layout, design, and construction involved problems and methods of general interest, and of importance to engineers and constructors engaged in similar river control work in this and many foreign countries.

Each project is considered in detail, a description being given of the preliminary investigations, including geology and river flow; dam and power-house design; construction methods, including the plant used, river diversion, employee housing and access facilities; relocations and adjustments in the reservoir area; initial operations; and a complete summary of project costs. The appendixes include a complete statistical summary of physical features on each project; reports of the engineering and geological consultants; summaries of hydraulic studies; lists of major purchases of material and equipment; and a report on the renovation of the Wilbur dam, a small hydro-electric plant. Bibliographies on each phase of the development are also included in the report.

Other published reports in this series include: "The Norris Project," published in 1939; "The Wheeler Project," 1940; "The Pickwick Landing Project," 1941; "The Guntersville Project," 1941; "The Chickamauga Project," 1942; "The Cherokee Project," 1946; "The Hiwassee Valley Projects," Vol. 1, 1946; "The Hiwassee Valley Projects," Vol. 2, 1947; "The Douglas Project," 1948; "The Watts Bar Project," 1948; "The Watts Bar Steam Plant," 1948; "The Fort Loudoun Project," 1949; "The Fontana Project," 1949; and "The Kentucky Project," 1950. Except for the Norris, Wheeler and Pickwick project reports, which are out of print, these reports are available from TVA Treasurer, Knoxville.

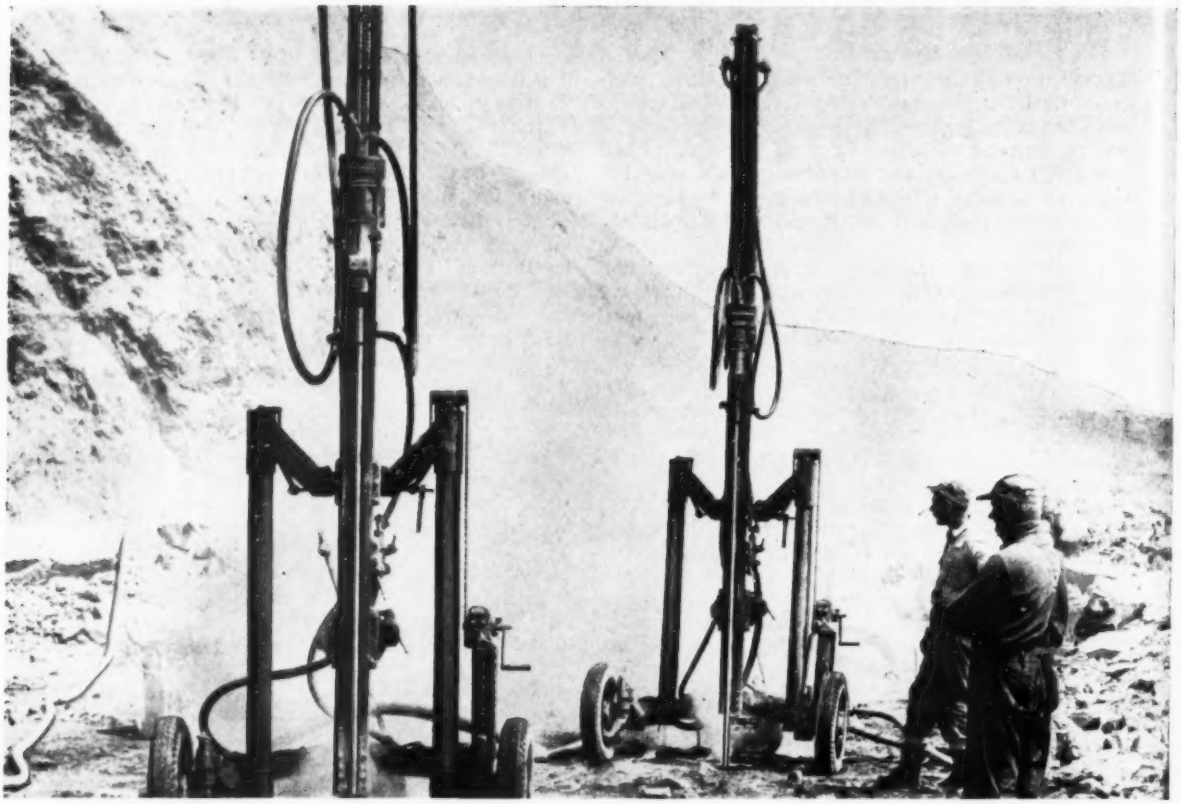
Dictionnaire Anglais-Français des Termes relatifs à l'Electrotechnique, l'Electrotechnique et aux Applications Connexes. By H. Piraux. Published by Editions Eyrolles, 61, Boulevard St-Germain, Paris-V, 1957; 6·3 in. by 9.5 in., 304 pp. Price in France, paper wrapper, fr. 1,850.

A very comprehensive and up-to-date English-French dictionary the scope of which extends to electronics as well as to related branches of science and industry. In addition to terminology proper, the author has had the excellent idea of incorporating in his compilation the abbreviations in current use in this country and the U.S.A. Specifically British or American terms are marked GB or USA; there is also a judicious choice of general engineering terms, and useful conversion tables are appended.

Surface Water Supply of Canada (Water Resources Paper No. 117). $3·00 per copy. Orders to be forwarded to the Director, Water Resources Branch, Department of Northern Affairs and National Resources, Ottawa 4, Ontario, the accompanying remittance to be in favour of the Receiver General of Canada.

The Water Resources Branch announces the publication of Volume 117 of the Water Resources Papers, Surface Water Supply of Canada. This Paper contains run-off data for the climatic years 1953–54 and 1954–55 for the Arctic and Western Hudson Bay drainage and for Mississippi drainage in Canada, which cover the whole of the Provinces of Manitoba, Saskatchewan and Alberta, and the Northwest Territories, as well as some adjoining areas in western Ontario and north-eastern British Columbia. The data presented are the results of the hydrometric operations which were carried out in these drainages during the period October 1, 1953, to September 30, 1955, in large part by the Water Resources Branch, although operations were facilitated by active co-operation received from provincial authorities and from a number of private agencies.

This Paper includes a short description of the organisation and scope of operations, an explanation of the method of tabulation, and 582 pages of stream-flow and water-level data for a number of rivers, streams, and lakes in the above drainages; also five pages of meteorological data pertaining to the operation of evaporation stations. The appendix contains a reference list of hydrometric records for these drainages, a list of available Water Resources Papers, and an index to the current issue.



Atlas Copco drills help make maritime history

The £300,000,000 St. Lawrence Seaway project, which will link the Great Lakes with the Atlantic, is now well under way. On many parts of this gigantic project Atlas Copco compressed air equipment has found a wide application. Our illustration shows Atlas Copco BVB 21 Wagon Drills boring holes for channel blasting. Chosen for their reliability and adaptability to a wide range of uses, these drills are proving their worth in the Seaway and on many other major projects.

Atlas Copco BVB 21 Pneumatic Wagon Drills

Weighing only 1,320 lbs, and designed for one-man operation, the Atlas Copco BVB 21 Wagon Drill will readily drill to any depths for practical purposes. Completely adaptable to any angle on uneven ground, it will drill to any angle within a 130° arc. Accommodating eight foot steel changes, it takes all bits from $1\frac{7}{8}$″ to 4″, and has a motor-driven chain feed, with throttles within convenient reach.

The feed motor is reversible to help the extraction of 'stuck' steels without wrenching.

The world's leading drilling combination

Atlas Copco Wagon Drills deserve the world's finest steels. Sandvik Coromant Extension Steels for long hole drilling have many superlative advantages. Cold-rolled from the toughest Swedish steels, they give smoother, faster drilling. Their large-diameter flushing hole—$\frac{1}{2}$″ in the standard $1\frac{1}{4}$″ equipment—gives a higher rate of advance, better cleaning of the hole, less wear on the bit and less risk of steels sticking. A further advantage is the patented Sandvik rope-thread. This gives a solid, positive connection—and, at the same time, makes screwing and unscrewing an extremely easy operation.

The combination of Atlas Copco drills and Sandvik Coromant Extension Steels, Integral Steels and Detachable Bits is responsible for the drilling of more than 1,000 million feet annually.

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The Atlas Copco Group puts compressed air to work for the world. It is the largest group of companies specialising solely in the development and manufacture of compressed air equipment. It embraces Atlas Copco companies or agents manufacturing or selling and servicing Atlas Copco equipment in ninety countries throughout the world. For further details of the equipment featured here, contact your local Atlas Copco Company or Agent, or write to:—Atlas Copco AB, Stockholm 1, Sweden, or Atlas Copco (Great Britain) Limited, Beresford Ave., Wembley, Middlesex.

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Turbines for Tuggen Station, Sweden

Recently the NOHAB Company (Nydqvist & Holm Aktiebolag, Tröllhattan, Sweden) received an order from The Swedish State Power Board for two turbines to be installed in the Tuggen power station on the Ume river (Northern Sweden). The turbines will be of the Kaplan type and each will have a maximum output of 80,000 h.p. at 125 r.p.m. under a net head of 26·6 m. (87 ft.). The diameter of the runner will be 5,700 mm. (18 ft. 6 in.). Our illustration shows a model of this turbine, which was selected by The Swedish State Power Board on the basis of comparative tests on models designed by different manufacturers. The first unit in the Tuggen power station will be in operation in November 1961 and the other in February 1962.

Claw-Type Cable Cleating

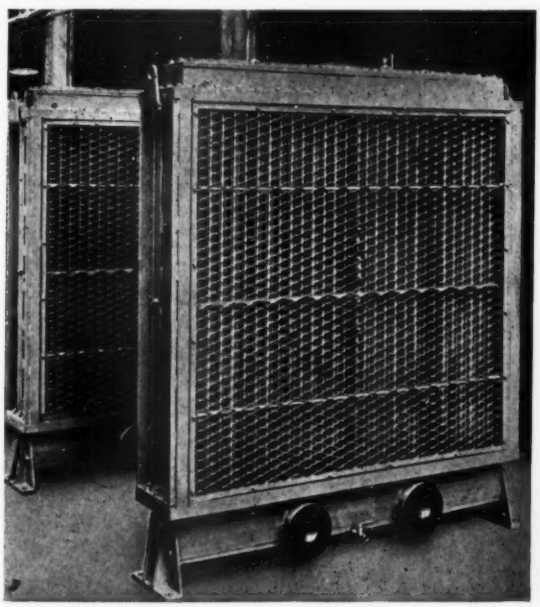
British Insulated Callender's Cables Limited, of 21 Bloomsbury Street, London, W.C.1, have developed a new claw-type cable cleating system which can be modified or adapted to suit any particular cable installation.

The cleats, consisting of two identical pressure die-cast halves, can be used singly or in groups mounted on suitable backstraps and they can be fixed to walls or steelwork for horizontal or vertical runs. They are made of aluminium alloy and a special finish can be applied when the cleats are used in very damp or corrosive atmospheric conditions.

A wide range of fittings is available and all the different sizes are interchangeable. The backstraps are of galvanised mild steel, drilled and tapped $\frac{3}{8}$ in. Whitworth for cleat fixing studs. A special fitting can be supplied for fixing one or two single-bolt cleats to steelwork.

Coolers for Priest Rapids

Heenan & Froude Limited of Worcester, are to supply more than 120 Heenan tubular air coolers to the English Electric Co. Ltd., for use in the Priest Rapids dam. The coolers will be used for the closed-circuit ventilation and cooling systems of the ten vertical-shaft water-turbine alternators, there being twelve coolers to each alternator. Two additional



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Holbits are either single-chisel or cross-type, and are supplied in all sizes and grades of carbide to suit any type of rock. They can be used with any type, size and make of drill.

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coolers will be supplied as reserves. Heenan & Froude have also secured a further contract from the English Electric Company for the supply of specially designed tubular coolers for the lubricating oil of the main thrust blocks of these sets.

Abstracts from the World Technical Press

Reversible Turbine-Pumps

Appended to an article on the subject reprinted from *The Engineer & Electrical Review* of January 17, 1958, a note draws attention to the fact that a turbine-pump was first installed on the European Continent as far back as 1931-32, when an 1,800 h.p. reversible unit was added to two vertical Kaplan turbines of traditional design at the Baldeneysee weir power house, near Essen. This type of machine, then a novelty, was selected with a view to refilling the great storage reservoir when the natural flow of the Ruhr sank below requirements. The machine, designed by Escher-Wyss Ltd. on the basis of extensive model tests, is still working economically after 25 years of service. Operating as a turbine from a head of 9 m. and with a discharge of 15,000 lit. per sec., it has an output of 1,500 h.p. at 256 r.p.m.; as a pump, running at 326 r.p.m. and consuming 1,770 h.p., it lifts 8,000 lit. per sec. to a height of 8·85 m., or 6,000 lit. per sec. to a height of 9·95 m. The maximum efficiency is 90% as a turbine and 78% as a pump. (*Tecnica*, No. 7, March 28, 1958, p. 327, 2 ff.)

An Italian Project in Ethiopia

An account is given of the activities of the Compagnia Nazionnale Imprese Elettriche (CONIEL) in Ethiopia and a survey of its studies for the development of the Hawash River and of its tributary, the Akaki River. The Coca project and the preliminary investigations involved are then described. Priority for execution was given to the development of the Akaki River, on which two plants are already in service. The first of these is a small variable-head plant incorporated in the Gheggia dam and the plant at Abba Samuel, which operates at a head of 95 m. Taken together, these plants produce 60 million kWh per annum. An automatic plant downstream of Abba Samuel is projected for a yearly production of 28 million kWh. The Hawash development is planned as a sequence of five power stations varying in yearly production between 39 and 168 million kWh, the various stations operating at heads varying between 10 and 45 m. The Coca plant, the highest upstream, will draw its supply water from a 1,150-million cu. m. reservoir created by a dam about 450 m. in length at the crest. In the Coniel project, the intake works are inserted in the left-bank section of the dam and consist of an inlet channel 27 m. in width, designed so as to ensure a supply of 150 cu. m. per second to the turbines, even when the reservoir reaches its minimum level. The inlet channel connects with a forebay 77 m. in length, trapezoidal in cross-section, and 20 m. wide at the bottom, which leads to three steel penstocks 3·8 m. in diameter by 81 m. in length. The outdoor power house, 18 × 70 m. in area by 14 m. in height, is equipped with three 15,000 kW vertical generating sets driven at 214 r.p.m. by Francis turbines designed to cope with the maximum discharge of 50 cu. m. per second. (Dr. Ing. Mario Bruni, *L'Energia Elettrica*, Vol. XXXV; No. 1, January 1958, p. 9; No. 2, February 1958, p. 132; 18 pp., 11 ff.)

Hydraulic Study of the Surge Chambers for the Alvito Power Station

The project for the Alvito power station development on the River Ocreza in Portugal includes designs for a relatively small reservoir, a penstock, with underground pressure tunnels and power station and an 8 km. tailrace channel running from the turbines to the River Tejo. Four turbines will be installed with a capacity of 40,000 kW each; they are intended to satisfy peak-load demands and to operate as pump-storage units at other times.

This paper is a complete hydraulic study of the surge chambers and shafts for the project. It discusses the various problems which arise in establishing a design of maximum efficiency for a dual-purpose power station of this type.

The tailrace tunnel between the power station and the Tejo is over 8,000 m. long and this has made a surge chamber system absolutely necessary. An additional problem has arisen because there is only relatively low pressure available immediately downstream from the power station and to overcome this, a vertical underground surge chamber has been adopted, immediately downstream from the power station and as near to it as possible.

A surge chamber must be so located that the pressure variations caused by water hammer are kept to a minimum and the best position in this case has been found to be near the tailrace at the junction of the pressure conduits. It has thus been found possible to damp surges resulting from partial load changes.

The Thoma formula:

$$F_{Th} = \frac{W_o^2}{2g} \times \frac{Lf}{H_o P_o}$$

is used to define the critical area of the chamber and an experimental coefficient of 0·7[6] for λ has been adopted for:

$$1 + \lambda \frac{P_o}{E_o} + \log_e (1 - A) \times \frac{1 - \frac{3C_o}{H_o}(1 - tg\ \mu)}{1 - \frac{3}{2} tg\ \mu}$$

where E_o is the velocity head, C_o is the load loss in the pressure conduit and $tg\ \mu$ is the relation between real and nominal operating conditions.

The study has shown that the two chambers situated between the reservoir and the power station will be an 8·80 m. constant-diameter shaft and a throttled surge chamber with a base diameter of 8·3 m. and a diameter of 5·8 m. at an elevation of 242 m.

For the latter it is important that the water level should not exceed 242 m. because this might reverse the flow in the conduit. To safeguard against this, the second surge chamber is extended to a level of 257·7 m. by a reinforced-concrete circular section.

Japan made Generators crossing the Pacific!

Toshiba

This hydro-electric generator, 22,000 kVA, two of which type are to be installed at the El Fuerte Power Station at Sinaloa, Mexico, is never too big for **Toshiba's** capacity. Such is in line, however, with **Toshiba's** policy to make its products "as small in size and as efficient as possible".

A plan of installing three 58,000 kVA generators at the Mazatepec Power Station in Puebla, Mexico, has been drawn up, and the construction is now under way. When completed, the latter is expected to be the most powerful power station in that country.

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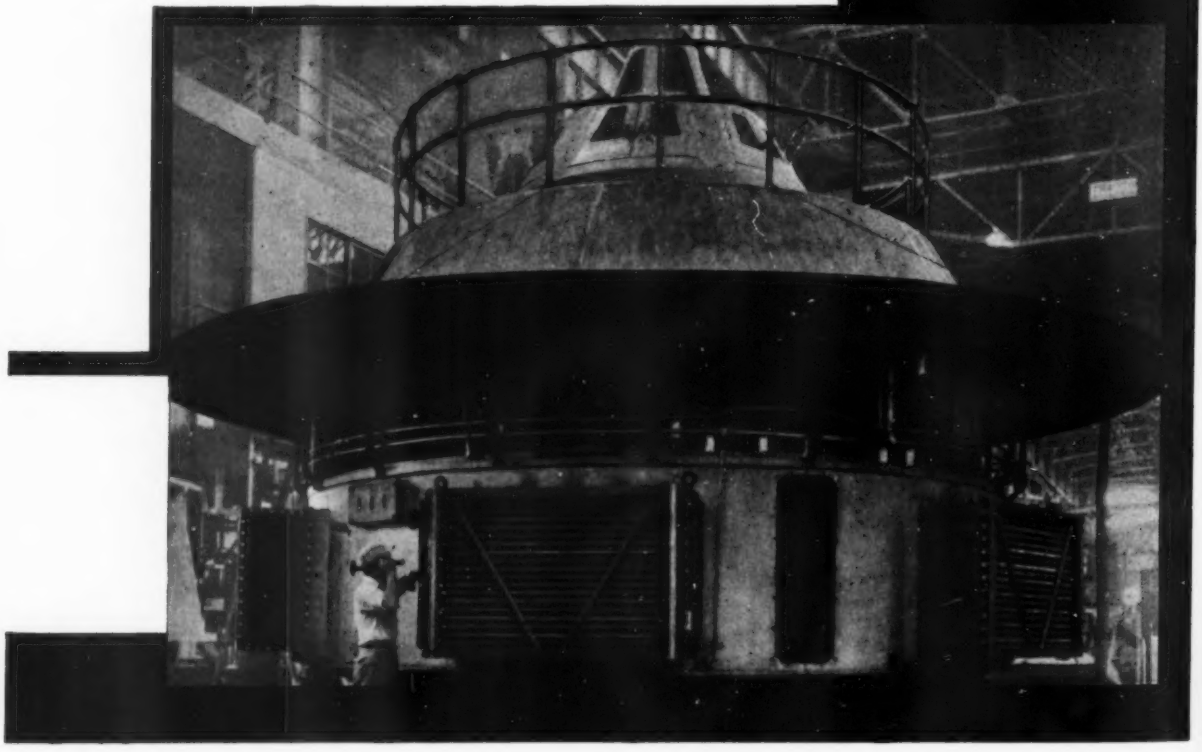

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Two different conditions were considered in calculating the diameters for the throttled chamber:

(1) When full load is applied instantaneously under flash-load conditions.

(2) Sudden full-load rejection.

By using the curves established by Calame and Gaden in their work "Théorie des Chambres d'Équilibre," it has been possible to make a purely theoretical calculation to determine the conditions under which a given load loss will occur.

An attempt was made to use the Calame and Gaden semi-graphical method to evaluate the surges but the results were unsatisfactory and it was replaced by the Schiffmann method as modified by Bouvard and Molbert. This calculation was first applied to a simple surge chamber installation but the method involves complicated equations and requires frequent verification. In this case, five different conditions were evaluated and the author gives the graphical results of his study to obtain the optimum design, allowing for an adequate working range of levels in the reservoir. Since Alvito is a dual-purpose turbine/pump storage installation the problems of stability are not the same for the two functions, and a graph has been drawn for a transition from idling to pumping under full load at a reservoir level of 180 m. and a discharge of 86 cumecs.

In considering the tailrace surge chamber, the most favourable curve shows a value of 13·28 m. for the amplitude of the ideal surge resulting from complete and instantaneous loading or unloading. This surge chamber will be a cylindrical shaft, 23·5 m. in diameter, and it has been calculated that the maximum upsurges and downsurges will be to levels of 97 m. and 51·5 m. respectively. The shaft will have concrete facing and the connection to the tailrace tunnel will be through a 2·59 m. diameter circular throttle section, the design for which will be established after scale model tests. An overflow spillway will be provided to prevent flooding of the power station if the level in the surge chamber should exceed the designed maximum under exceptional conditions. (Fernando Manzanares Abecasis, *Electricidade*, No. 6, April–June 1958, p. 109, 13 pp., 13 ff.)

Water-Turbine Alternators

A comprehensive description in English is given of the latest Czech designs of water-turbine-driven alternators, with special stress on large units. In the first part of the article, devoted to electromagnetic design, the authors deal with the rating of the alternator, i.e., determining its main active dimensions, selecting the stator winding, the electromagnetic and the excitation circuit. In the second part, constructional and technological design are discussed, and separate paragraphs deal with the location of the thrust and guide bearings, the selection of the type of magnetic rim, and method of pole fastening, ventilation, frame design with active iron and winding, erection procedure, transport, balancing, etc. The article concludes with a detailed description of the three 60 MVA alternators supplied by the ČKD group of engineering works (Českomoravská-Kolben-Daněk) for the Slapy power station on the Vltava river, some 15 miles upstream from Prague. From the final paragraph, we understand that the ČKD concern has now in hand several 75 MVA units for the Lipno underground power house, the top stage of the great Vltava development. (Dipl. Eng. B. Riha and J. Pelnář, *Czechoslovakia Heavy Industry*, No. 12/57, p. 4, 11 pp., 20 ff.)

NOTE: This issue of the above mentioned journal, published on the occasion of the 250th anniversary of the Czech Technical University, also contains an article on "Insulation Tests of Alternators, Steam or Water Driven." (Dipl. Eng. Jindřich Kraemer, p. 16, 16 pp., 32 ff.)

Yugoslavia's Hydro Resources

From a general survey of the country's power potential, it appears that Yugoslavia's rivers constitute its main power resources. Thermal power was leading hydro production in 1939 (672 million kWh against 478 million kWh per annum); the figures for 1956 show that hydro power, at 2,869 million kWh, was more than double the thermal production (1,178 million kWh), corresponding to an installed capacity of 16,500 MW. (*Indian Journal of Power and River Valley Development*, Vol. VII, December 1957, No. 12, pp. 25/26.)

Regulation of Frequency and Energy Exchange in Electrical Systems

An outline is given of the methods applied by the Study and Research Board of Electricité de France in the course of a general theoretical investigation of control problems, in which it is aimed to take into account all the main parameters intervening in control circuits. Following a brief description of the control circuits of the power-phase-energy type, the author submits the equations which govern the working of these circuits; at the same time, he points out that an analytical solution of these equations is unlikely to produce useful information unless certain simplifying hypotheses on the nature of the systems under investigation are allowed; if this is not the case, the use of an analog computer cannot be dispensed with. The purpose of the investigation undertaken was to define the values of the characteristic parameters of control which ensure optimum control, viz., slope of control, regulating energy of control, stabilisation coefficient, characteristic times of secondary control. In actual practice, quality of control can only be defined statistically, and the investigators decided to select the value of the typical gap of frequency variation and the value of the typical gap of the variations of interconnection power. It is then explained how the investigation under review makes it possible to select those values of the characteristic control parameters which reduce to a minimum these typical gaps if the uncertain characteristics of load variations in the system are known. It is, however, advisable to state precisely that in normal practice, there is no certitude that these optimum values could be adopted. An improvement in control quality can indeed be finally obtained only by a more intensive working of the machines submitted to control. It may prove necessary to compromise between the pursuit of good-quality control and the desire to avoid putting too great a strain on the machines. It is perfectly obvious that this strain will be all the less for an equal quality of control as the number of machines submitted to secondary control is greater. It therefore fol-

lows that the greater the number of machines included in a control system, the closer is it necessary to draw to the theoretical optimum quality obtainable with that particular type of control. In this field the advantages of the power-phase-energy control are particularly conspicuous. B. Favez, EDF Study and Research Board, *Bulletin Technique de la Suisse Romande*, Vol. 84, No. 13, June 21, 1958, p. 221, 9 pp., 5 ff.)

Flow Studies

This paper deals with recent developments in fluid flow through pipes and channels, and advocates a new method of approach for rough turbulent flow through pipes. Depending upon the Reynold's number N_R, a pipe of given relative roughness may have any of the five zones of flow, viz., laminar, transition from laminar to turbulent, smooth turbulent, transition from smooth turbulent to rough turbulent, and rough turbulent flow. The friction flow equations as given by Prandtl and Karman for smooth and artificially roughened pipes based on Nikuradse's experiments, and the transition equation for commercial pipes as given by White and Colebrook, are discussed at length. An attempt has also been made to extend the Prandtl's rough-pipe equations to flow through rough channels, and the various limitations under which this is possible are pointed out. Using Prandtl's rough turbulent equations as a basis, the following simple relations have been obtained for flow through rough pipes and channels, viz. $\frac{1}{f} = 34{\cdot}5 \left(\frac{R}{K}\right)^{1/3}$ giving Chezy's $C = 47{\cdot}0 \left(\frac{R}{K}\right)^{1/6}$ and Manning's $N = 0{\cdot}0315\ k^{1/6}$. It has further been shown that the above relations are true for values of $\left(\frac{R}{K}\right) \geqslant 4$, a limitation which in the author's opinion has never been pointed out by other writers. Also using the above relations, the following new formula for the design of pipes when the flow is rough turbulent has been developed $d^{16/3} = \frac{Q^2 L k^{1/3}}{217\ hf}$. The advantage of this formula is that when the given elements of flow are hf, Q (or V), L, ρ, μ, k, the diameter of the pipe can be obtained directly, a problem which till now could be solved only by trial and error. (R. M. Advani, *Irrigation and Power*, Vol. 14, No. 4, October 1957, p. 532, 16 pp., 4 ff.)

Upper Colorado River Project

The recent award of the Flaming Gorge dam contract marks the start of the second major phase of the Upper Colorado River development. This thin-arch structure, sited on the Green river in north-estern Utah, will rise 490 ft. above bedrock and thus become the seventh highest concrete dam in the U.S. Other characteristics are: 150 ft. maximum thickness, 1,180 ft. crest length, and 6,047 ft. crest elevation. The volume of concrete involved is expected to be 922,000 cu. yards. The most unusual constructional feature will be heavy-media aggregate separation—removal of aggregate having less than 2·5 specific gravity. All aggregate for Flaming Gorge from No. 8 screen up to 1½ in. in size will be so processed to satisfy the specifications which call for a maximum of 2% of rock below 2·5 specific gravity. This condition arose out of the scarcity of good aggregate sources in the predominantly shale area around Flaming Gorge. In fact, the deposits recommended for contractor use have about 20% rock with less than 2·5 specific gravity, and the light rock in the intermediate size range is subject to damage from the freezing and thawing cycles generally occurring at high elevations. A similar but less strict specification applies to the Glen Canyon dam, where the heavy media processing plant is just being tested, and where lightweight particles will be removed only from aggregate to be used in exposed concrete. This is due to the greater thickness of the dam and also to the less severe climatic conditions than at Flaming Gorge. On the other hand, concrete cooling will not be such a problem at Flaming Gorge as at other recent concrete dams in U.S. Though primarily planned to provide river regulation, Flaming Gorge will produce power from three 36,000 kW generators. Preliminary work for a temporary access road to the dam site and for the new project town of Dutch John, Utah (streets, utilities and residences), is under way. The lowest bid for Flaming Gorge dam was submitted by Arch Dam Constructors of Omaha, a joint venture headed by the Morrison-Knudsen Company and Peter Kiewit Sons. The latter firm's office at Omaha will handle the early construction planning. (*Engineering News-Record*, June 19, 1958, pp. 26/27, 2 ff.)

Half a Century of Service

The first penstock erected at the Auzat plant on the Ariège river has just completed fifty years of service and a foremost specialist has availed himself of this opportunity to review the progress achieved in constructional methods and techniques during the past half-century of penstock manufacturing. In view of the equipment penstock manufacturers had at their command fifty years ago, the first Auzat penstocks marked a daring advance. This pipeline, a mere 1·00 m. in diameter, operates from a head of 420 m. at the rate of 3 cu. m. of water per second, and consists of 6·4 m. long sections made up of four 1·6 m. sleeves. All the joints are riveted. The outstanding feature is that for the first time steel plate had superseded iron plate in the construction of a penstock. In addition, plate thickness, which had never before exceeded 20 mm., had been increased to 32 mm., and the rivets used were 32 mm. in diameter. All this was done at a time when steel-plate manufacturers still lacked adequate industrial experience. The author describes the many difficulties which cropped up at both the manufacturing and assembly stages and the many serious mishaps which occurred between the first pressure tests and the commissioning of the penstock. In fact, in spite of all the care taken in manufacturing, the pipe sections were neither perfectly round, nor perfectly straight. Nevertheless, as the author shows, the results of the observations made on the Auzat penstock fifty years ago led to developments which constitute an outstanding contribution to the improvements since achieved in penstock manufacture. The author reminds us in his conclusion that in regard to reduction in weight, cost and dependability in operation, hardly any branch of engineering has achieved more spectacular success in the course of the past fifty years. (Georges Ferrand, Président-Directeur Général, Société Dauphinoise d'Etudes et de Montage, Grenoble, *La Houille Blanche*, Vol. XIII, No. 2, March–April 1958, p. 116, 7 pp., 4 ff.)

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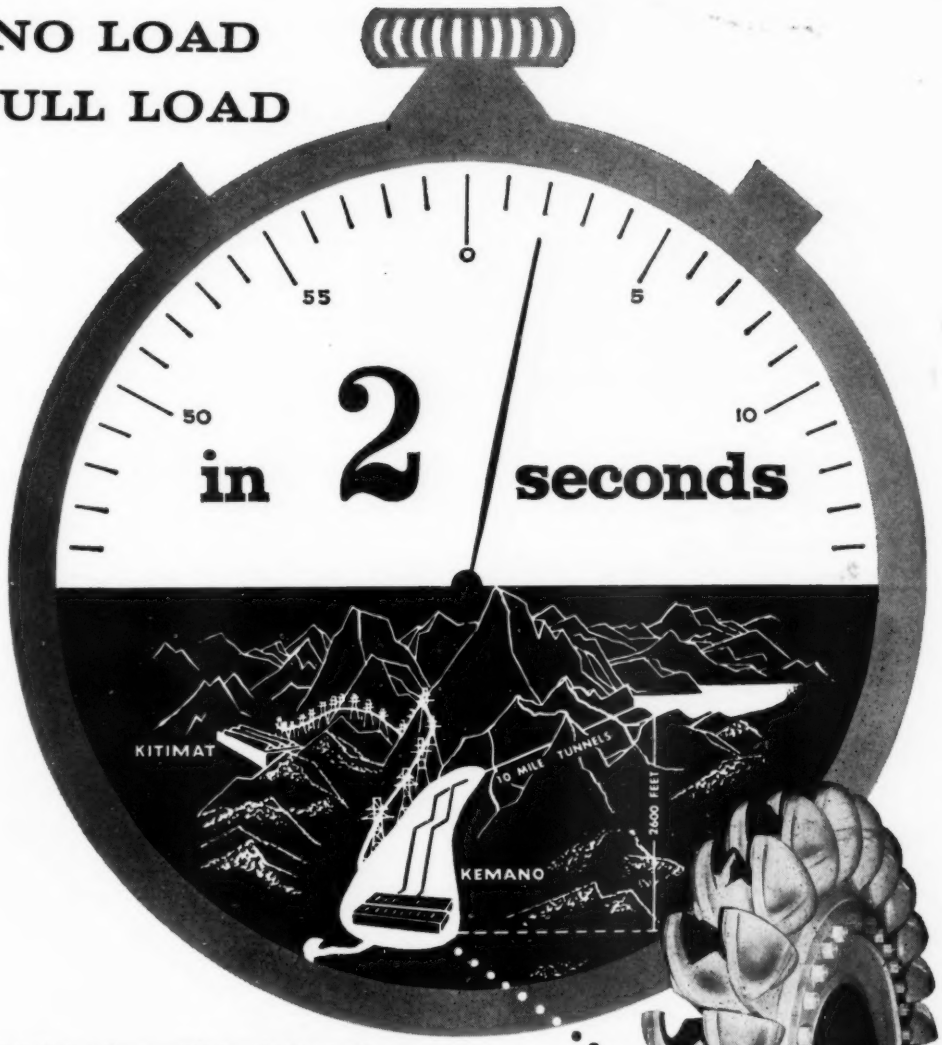

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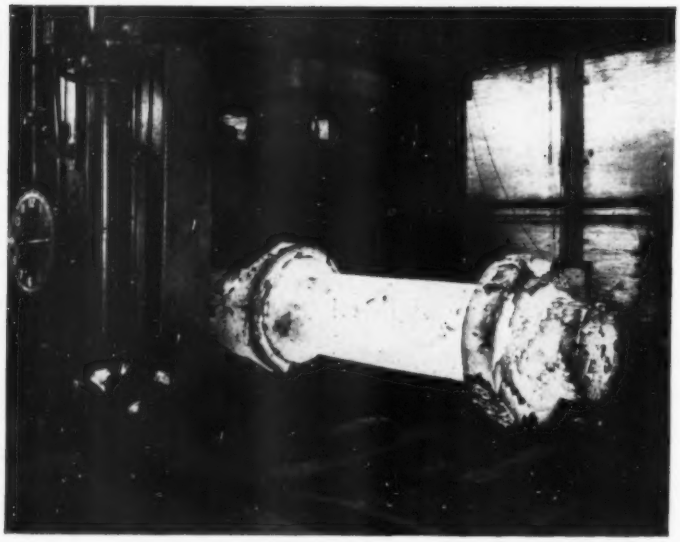

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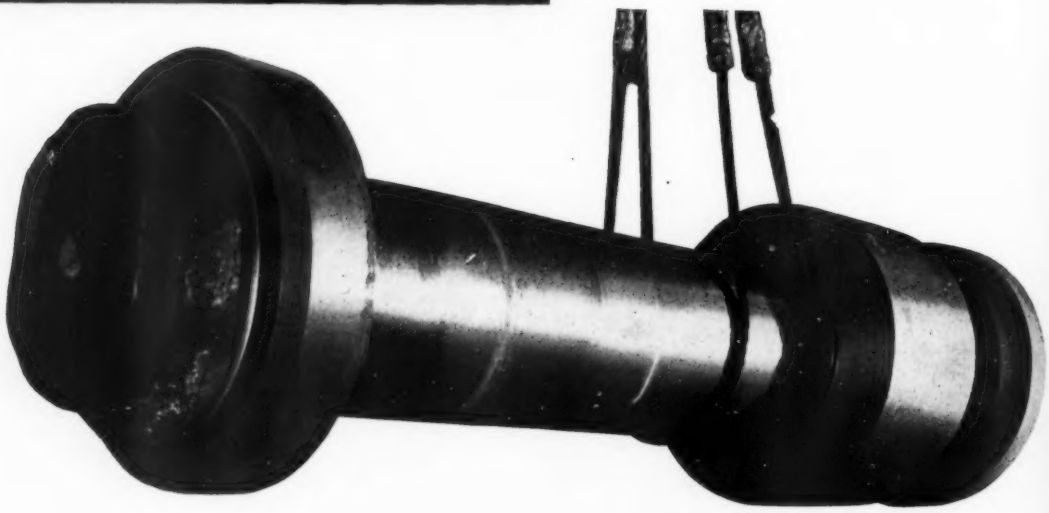

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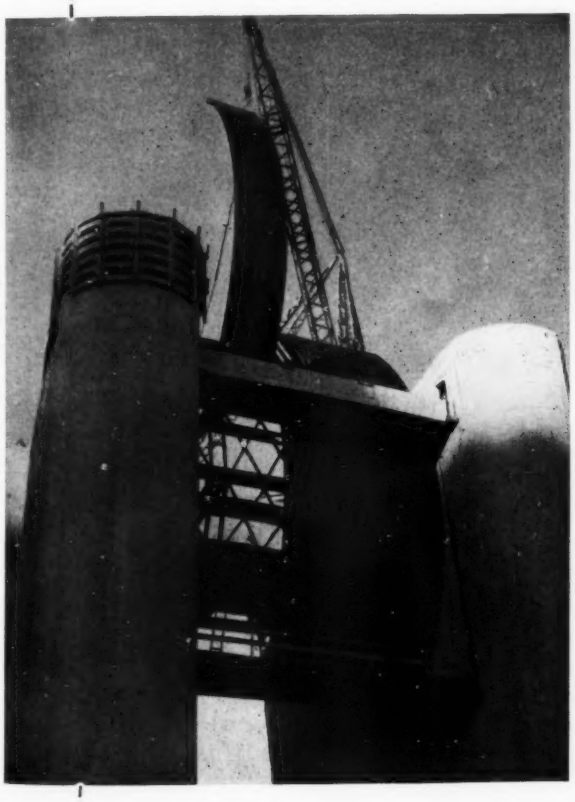

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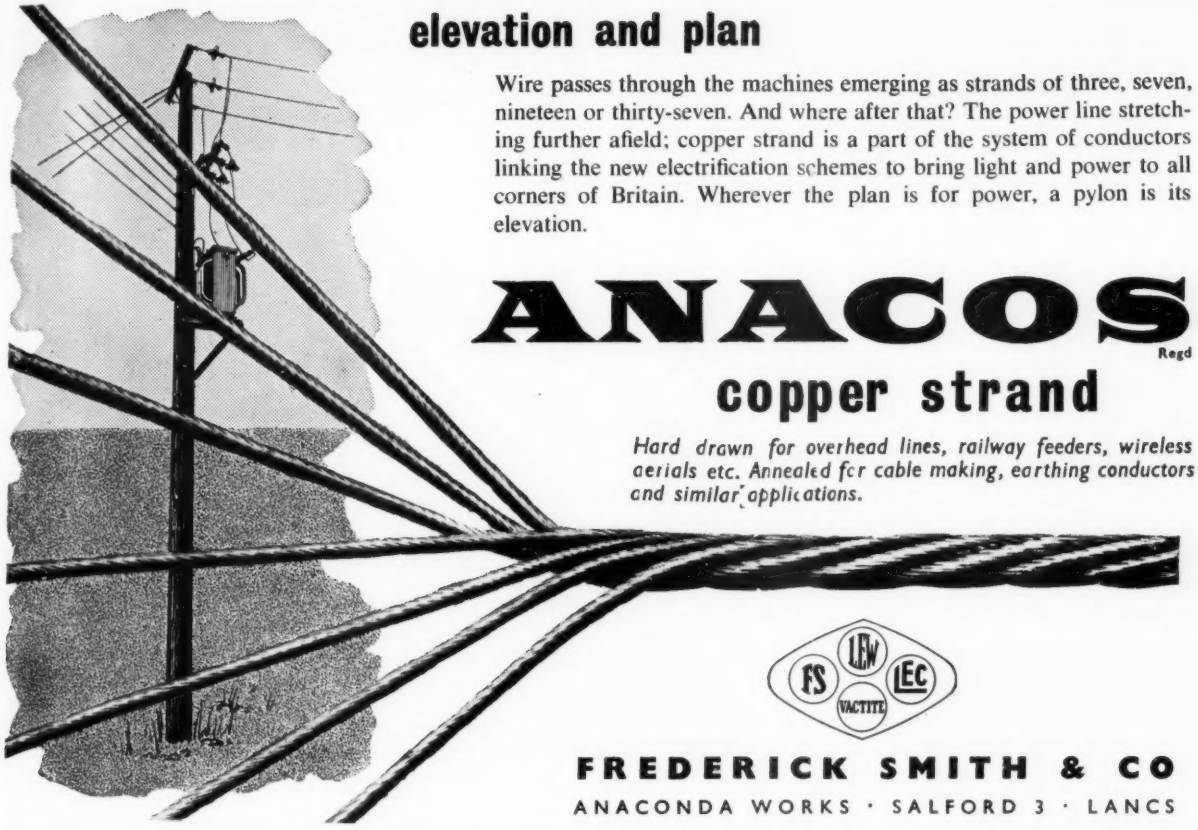

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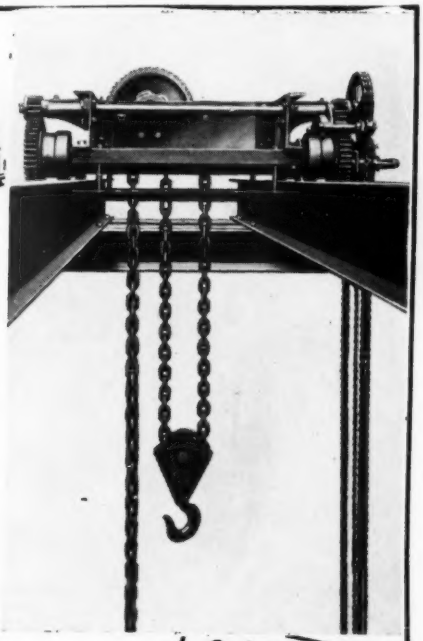

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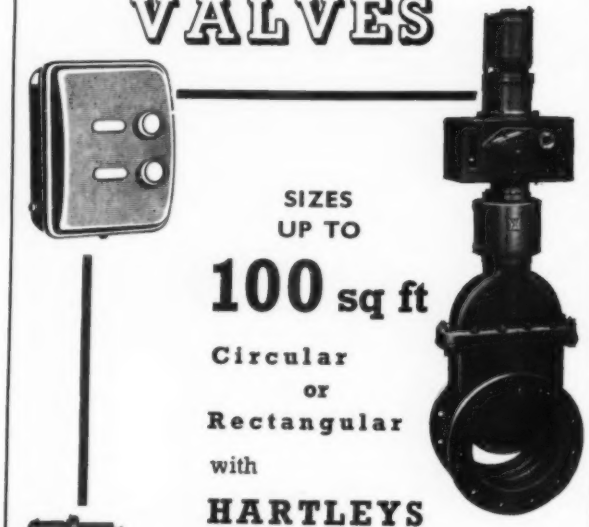

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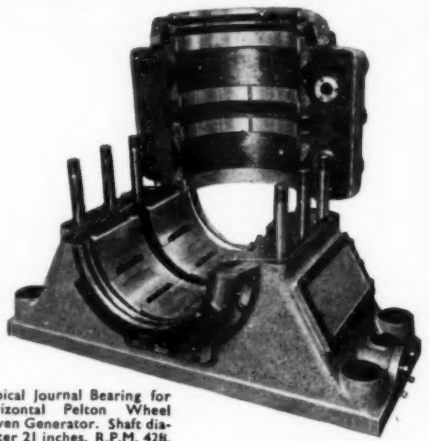

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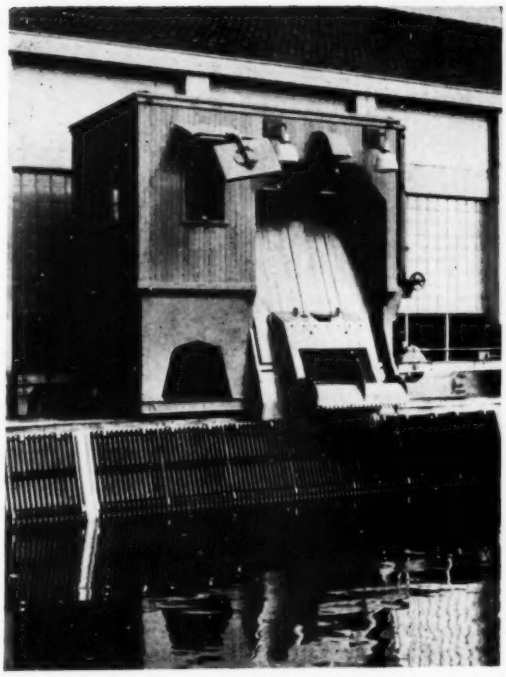

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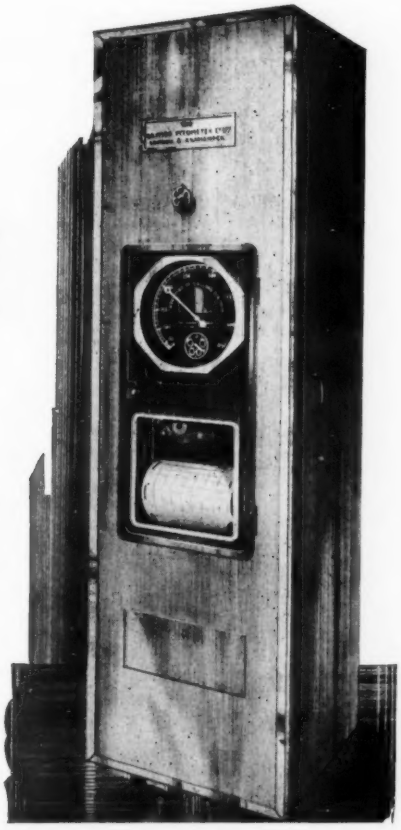

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